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DEVOTED TO

SCIENCE AND THE MECHANIC ARTS

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PREFACE

It is customary, in observing an anniversary, to review the past. And the past of the JOURNAL OF THE FRANKLIN INSTITUTE is, indeed, closely linked with those developments in basic and applied research which have created our twentieth century world and promise to lead man further along the road to control of his environment. For 125 years the JOURNAL has remained an unspecialized technical publication in accord with the policy enunciated in a prospectus of 1825, "to diffuse information on every subject connected with the useful arts." Its facilities have been available consistently to contributors from any field. Its volumes contain many significant firsts in scientific history. The sweep of scientific advance for the past century and a quarter stands revealed in its pages.

The founders of the JOURNAL were practical men, aware of the importance of historical record, but concerned primarily with the dissemination of ideas and techniques and their application to contemporary problems. It is appropriate, then, that this commemorative issue be opened by a brief history of the JOURNAL, and that the remainder of the issue be devoted to "Science and Tomorrow," a group of papers telling about future developments in many fields of science and technology. So, in the belief that trends and objectives could be formulated by scientists of vision, the editors invited eminent authorities to contribute papers in their fields, defining our objective in these terms: ". . . The commemorative issue will predict future developments in science and technology, based on the considered opinions of today's leading authorities. The issue will be a composite picture of what can reasonably be expected in the basic physical sciences . . . , as well as what advances may be made in such fields of the applied sciences as aeronautics, communications, etc."

The response to our invitations was most gratifying. The editors of the JOURNAL are proud to present this symposium and gratefully acknowledge our indebtedness to its contributors. We believe that this issue will be read with great interest by scientists, engineers, students and laymen, and hope that by definition and delimitation of existing problems, it will in some measure contribute to the advancement of science.

HENRY B. ALLEN
Editor

December 15, 1950
Philadelphia, Pa.

THE FRANKLIN JOURNAL,

AND

AMERICAN MECHANICS' MAGAZINE;

DEVOTED TO THE

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Under the patronage of the Franklin Institute of the State of Pennsylvania.

EDITED BY Dr. THOMAS P. JONES.

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1826

THE JOURNAL OF THE FRANKLIN INSTITUTE:

Its First One Hundred and Twenty-Five Years

BY

THOMAS COULSON

The Franklin Institute

The nineteenth century was the most productive period in our civilization. Greater material progress was made during those one hundred years than in any similar period of man's existence, and the half century which followed has revealed a quickening tempo in progress. This JOURNAL, which has been published without interruption since January, 1826, is the chronicle of man's progress in science and technology during the greater portion of that time. More than a mere record, it made its appearance at a most significant moment in national history, at the time of transition from hand crafts to factory production, and became symbolic of the age. The contents of the early numbers serve to remind us that before architects and engineers came carpenters and smiths, and that these were the intermediaries between simple and unspecialized Man and our highly specialized civilization.

We think of science as a coherent system, but perusal of the JOURNAL's pages shows us that it is something that has grown and is growing, and that as it grows, it progressively affects man's life. Anything that grows and develops can only be understood by studying it historically. Any organism, movement, or civilization must be studied in time, and in so far as we concern ourselves with science as something in progress, so we must study it in history. The pages of the JOURNAL are illuminating records of that progress and provide an authoritative chronicle for a study.

The progress of science presupposes the unrestricted communication of all judgments and results. At the time when The Franklin Institute was founded in 1824, the members were cognizant of the need for such an organization in the city of Philadelphia, but their zeal was not to be satisfied with the filling of a local need. The need might be felt most acutely in a crowded city where manufactures and labor were concentrated, but it existed only to a lesser extent throughout the whole nation. The members of the Institute proposed to produce results by experiments and to express judgments in their lectures. But how were they to announce these to the nation? How were the members to reach the vast audience beyond the range of their voices, and how were they to learn what was being said and done beyond the limits of their own hearing?

(Note—The Franklin Institute is not responsible for the statements and opinions advanced by contributors in the JOURNAL.)

The printing firm of Atkinson and Atkinson had offered to print the papers and accounts of Institute activities in the *Saturday Evening Post*, and the publishers of the *American Farmer* made a similar offer but, while it was conceded that this might furnish desirable publicity for the Institute, it would not solve the problem confronting the wishes of the members. The bar, the medical profession, the merchants, and the farmers had their specialized journals, but in a community which was in process of transition from the handcraft to the production stage, the artisans, the mechanics, and the manufacturers had no periodical devoted exclusively to their interests. The nearest approach to a technical journal in the country was to be found in Silliman's *Journal*. This, like the publications of the learned societies which were springing up all over the country, was less concerned with the requirements of practical men than it was with the work of the scientist. The need existed to gratify the wants of the great mass of people who had no opportunity to receive a technical education but who were avidly reading any scrap of information on the new tools and processes which were being developed for the enrichment of life.

Members of the Institute were aware that certain obstacles must be overcome before their aspirations could be realized. In the first place, there was the question of financing the publication of a journal. As the Institute had no source of income beyond the members' subscriptions, and the finances were already burdened with the cost of constructing a building to house the many activities, the Board of Managers naturally shrank from accepting any additional responsibilities. There was, too, the matter of finding a suitable man to undertake the editorial functions. In a circular letter sent to the newspapers, the Corresponding Secretary, Peter Browne, had emphasized the need for the projected journal and had added his views upon the qualifications of the editor. "He should be a man of education and talents, particularly versed in Natural Philosophy and Mechanics, to enable him to write original essays on subjects connected with the arts. He should be possessed of industrious habits, for he must collect from foreign and domestic journals everything that will tend to improve the mind of the artisan. He should be a man of quick apprehension and ready with his pen so that he might catch the heads of a Lecture to present to his readers. He should be a man of the strictest integrity, devoted to their interest, that he might enjoy the confidence of his fellow citizens."

Browne then coyly remarked "the gentleman who has been appointed professor of Mechanics to the Franklin Institute possesses all these qualifications, and has been prevailed on to dedicate them to your service. . . . His journal will be published under the auspices of the Institute and will consist not only of their transactions, but such essays and information as their professors, managers, and members, and others shall contribute."

The paragon to whom this referred was Dr. Thomas P. Jones, then holding a teaching post at Oxford, N. C. In appointing him a professor at the Institute school, the Board of Managers had resolved "that the Board deem it expedient that a mechanical journal be published under the auspices of the Institute and in case Dr. Jones will undertake to publish such a work the Board will use its influence to extend its circulation." It is quite evident from the correspondence which followed that a good deal of importance was attached to the publication of the journal, and it is equally clear that Jones was confident the promised support of the Institute members would make the enterprise sufficiently remunerative to compensate him for the small salary ($400) appropriated to pay for his services as professor.

Two weeks after he had accepted the appointment, Jones was being urged to issue a prospectus of the journal. He was unable to make arrangements which would permit him to arrive in Philadelphia before December 1825, and it was felt he should be ready to issue the first number of the periodical in January. Peter Browne wrote him: "The publication must be announced immediately to prevent the members from subscribing to a republication of the *London Mechanics Journal* made in New York, for which a subscription paper is now handing about the city. If your prospectus is delayed 'til December you will have lost many valuable subscribers."

We shall have more to say about this New York "republication" but for the moment let us follow Dr. Jones' actions. He was so anxious to meet with the wishes of the Institute that he got out his prospectus on August 1st, 1825. In it he declared:

"Shortly will be published

THE

FRANKLIN JOURNAL

AND

MECHANICS MAGAZINE

UNDER THE PATRONAGE

OF THE

Franklin Institute of the State of Pennsylvania for the Promotion of the Mechanic Arts,

edited by Dr. Thomas P. Jones, Professor of Mechanics in the Institute."

The object of the periodical as defined in the prospectus was

> . . . to diffuse information on every subject connected with useful arts. In the accomplishment of this design the editor will freely avail himself of whatever has been published elsewhere; but he is determined, at the same time, to give to the work a character truly American. With this view, a particular description will be given of the various useful inventions and improvements made in our own country; and in selecting articles from foreign works, those of course will be preferred which are more immediately applicable to the arts and manufactures of the United States. A list of patented inventions will be given, accompanied with free remarks upon their utility and originality. Inventions either new, or not generally known, will occupy a large portion of the work. It will also contain brief reviews of works, whether foreign or domestic, which treat on any of the useful arts; descriptions of the productions of mechanical genius, remarkable either for their magnitude or for the skill and patience manifested in their execution; biographical notices of individuals who have distinguished themselves by their improvements or pursuit of the useful arts; exemplifications of the intimate connection which exists between science and skill in the mechanic arts, and of their dependence upon each other for the attainment of the utmost perfection of either.
>
> The transactions of the Franklin Institute and an abstract of the lectures delivered will always receive a distinguished place in its pages.
>
> In the execution of this plan the Editor will not stand alone; he will be aided by his colleagues in the Institute, and by a number of other gentlemen distinguished by their zeal and capacity. His own resources are not inconsiderable as he has through life devoted a long portion of time to the attainment of knowledge in the theory and practice of the useful arts; has associated freely with mechanics and possesses sufficient skill to subject to the test of experience most of the processes which require an acquaintance with operative mechanics or chemistry; he pledges himself, therefore, never to mislead his readers on these subjects.
>
> The Editor will not be sparing of either time or money to render the work as perfect as possible. He is more anxious to make it useful than profitable, and is aware that if the latter quality is attained it must be through the medium of the former.

The volumes he proceeded to issue are proof that Dr. Jones was a man of his word, and did not believe in making idle promises. His words found literal verification.

The task was not without its initial difficulties. Some members wanted the new journal to be issued in the form of a newspaper which, they judged, made easier reading, but the majority favored a pamphlet "which was more respectable and permanent." Fate had a hand in the decision. In order to understand this we shall have to revert to the "republication" of the *London Mechanics Magazine*, of which Peter Browne had made mention in one of his letters to Jones urging haste.

On February 25, 1825, was issued a modest sixteen page weekly journal called *The Mechanics Magazine, Museum, Register, Journal, and Gazette*. The publisher was James V. Seaman, of 252 Broadway, opposite the Park, New York, and the printer was William Van Norden. In the preface to the first half-yearly volume it was explained that "at the commencement of the publication it was professedly intended to be a copy of the *London Mechanics Magazine;* but a little experience convinced us that the plan was objectionable for this simple reason, that

the London Magazine contained much local matter, that would afford little if any instruction or entertainment to the generality of our readers." This conviction must have been reached at an early stage, for the masthead of the fourth issue had the word "American" inserted above the title. When the title page of the first complete volume was printed for inclusion in bindings it bore the title *American Mechanics Magazine.*

The little weekly drew heavily upon the columns of its British prototype and other periodicals for its material, but it quickly developed a lively correspondence column in which subscribers asked for information which would enable them to solve personal problems, or to describe freely their improvisations. The journal appeared to be well established when, on December 10, it was announced that C. S. Williams had assumed responsibility for publication. His tenure of office was brief, for the preface to the second volume, which completed the issues for 1825 contained this passage:

> It was thought that a weekly publication, principally devoted to mechanics, would meet with success, and seeing the many works of the same nature daily issuing from the British press, led us to believe this country, never backward in improvement, would, and we are proud to say has, given us a fair share of support. It is not the want of encouragement, therefore, that has determined us to cut short the present volume after encountering many and various difficulties, but with a view to the more general encouragement of science and the discoveries of our own citizens. We have passed our list of subscribers over to the Franklin Institute of Philadelphia, from whence the work under the title of the Franklin Journal and Mechanics Magazine will continue under the guidance of that eminent mechanic, Professor Jones.

Dr. Jones had solved one of his problems by absorbing his principal competitor. The title adopted was not his own choice. He had expressed a preference for "The Journal of the Franklin Institute," presumably with the expectation of securing the Institute's members wholesale as subscribers, and to exploit the prestige already acquired by such a well supported organization. Strangely enough, the weight of opinion was in favor of the title adopted. Perhaps the Board of Managers did not wish to associate the Institute too closely with an experiment in journalism.

The first issue was intended to be ready for circulation early in January but, although it bears the date of the first of that month, publication was obviously delayed since the number contains communications dated as late as the 19th. The publisher's name was given as Judah Dobson, 103 Chestnut Street, Philadelphia, and the printer was Jaspar Harding. The issue comprised 64 pages, sparsely illustrated. In an introductory address the Editor announced that the subjects to be treated would embrace:

1st. The transactions of the Franklin Institute, and of other similar establishments.—2nd. Mechanics and Natural Philosophy.—3rd. Chymistry, particularly in its application to the arts.—4th. American inventions and discoveries, whether patented or not.—5th. American manufactures.—6th. Internal improvements.—7th. Natural History.—8th. Mineralogy.—9th. Botany.—10th. Mathematics.—11th. Architecture.—12th. Popular education.—13th. Husbandry and rural affairs, particularly as regards the implements used; and the production of silk, flax, wool, cotton, dye-stuffs and other articles employed in manufactures.—14th. Mechanical jurisprudence.—15th. Foreign journals, inventions, discoveries, and patents.—16th. Notices and reviews of publications relating to Arts and Manufactures.—17th. Miscellaneous articles, consisting of recipes, processes, etc.

Original contributions were solicited but intending contributors to the JOURNAL were admonished "always to keep in view that its main object is to diffuse information among artisans and manufacturers; and that therefore it is necessary to write in a style as familiar, and as little technical, as the subject will admit."

In the first issue there was displayed a commendable desire to hold the borrowings from foreign sources to a minimum for, in addition to articles on Institute activities there were original articles by two prominent Institute members. The dean of American scientists, Dr. John Hare of the University of Pennsylvania, furnished an article on "Specific Gravity," and Peter Browne (the corresponding secretary) one on "Mechanical Jurisprudence," the first of a series which was to embrace all the legal aspects of invention, manufacture, and labor relations. The editor had intimated in his "address" to readers it was intended that the JOURNAL should publish accounts of the work performed by the Pennsylvania Society for the Promotion of Internal Improvements, which had been established in 1824 by Colonel John Stevens and Benjamin Dearborn. They had engaged William Strickland, the Institute's professor of architecture, to visit England and to submit a report upon railroads, canals, roads, bridges, and steam engines. One of these reports, on the Hetton Railroad, was included in the first issue of the JOURNAL, and so appeared at a time when Americans were still hoarse from cheering the opening of the Erie Canal. This was the forerunner of many other articles on this rapidly developing form of land transportation.

Of especial significance in view of the role that was to be played by the Institute in the standardization of screw threads, is a note by the editor in this very first number asking for information on the cutting of screw threads.

With the issue for January, 1828, the Institute assumed full responsibility for publication and its name replaced that of Judah Dobson as publisher on the title-page. The assumption of responsibility was probably prompted by an intimation that Dr. Jones might have to resign his professorship and relinquish his ownership of the JOURNAL, for he was appointed Superintendent of the Patent Office in April, 1828,

and moved to Washington to discharge his duties As a mark of their appreciation for his services the Board of Managers of the Institute appointed him editor of the JOURNAL for the duration of his life. This association continued until it was broken by death in 1848.

At the end of 1828 it was felt advisable to acknowledge more openly that it was the official organ of the Institute. The title was thereupon changed to its present form, although for some reason not easy to explain, the title-pages of the two volumes for the year 1828 bear the new name, whereas the separate issues were entitled *The Franklin Journal*. This confusing detail sometimes leads to the erroneous belief that the title had been changed in the previous year.

In the prospectus announcing the forthcoming publication, mention had been made of the intention to give a description of patented inventions, with remarks upon their originality and utility. Since this was to develop into a unique feature of the JOURNAL it is worth noting that this was only accomplished after a strenuous battle against the wishes of the conservative Patent Office officials, supported by the opinion of successive Attorney-Generals. The official attitude was that the public did not possess the right to examine unexpired patents and that, therefore, copies of the patents could not be provided for the Institute's purpose. Peter Browne, the Corresponding Secretary, was a pertinacious and pugnacious lawyer, who threw himself wholeheartedly into the struggle to gain the Institute's right to obtain and to comment upon all patents that were of interest to the members. He carried the fight up to the President (John Adams) before his persistence bore fruit.[1]

The promise to keep readers informed upon the issue of interesting patents was fully maintained after the right to secure them had been gained, and remained a prominent feature of the JOURNAL to the close of 1859, except that the "Remarks" were discontinued after the death of Dr. Jones. His accession to the post of Superintendent of the Patent Office enabled him to devote special attention to the record of patents published in the pages of the JOURNAL, and this endowed its issues with an unusual interest. In the official publications of patent records no mention was made of the claims of the applicants before 1843. Once the Institute acquired right of access to this information in 1828, the JOURNAL published abstracts of the specifications and the claims in full (except between March and October, 1836). The JOURNAL, consequently, is the only source of reference to the specifications and claims of patents between 1828 and 1842, with the slight exception noted above.

However, although this was the time when the Patent Office was being bombarded with applications for patents of new inventions, they were not the editor's principal concern. The dissemination of knowl-

[1] The story of this struggle for the patents is told, with extracts from the correspondence, in E. S. PANIAGUA, "American Inventor's Debt to the Institute," JOURNAL OF THE FRANKLIN INSTITUTE, Vol. 247, p. 1 (1949).

edge was foremost in the minds of the promoters, and they adopted what was thought to be the best means for attaining their purpose. In the preface to the first completed volume the editor had explained that "Originality, although to a certain extent desirable has not been deemed of primary importance; the end proposed will probably be best attained by judicious selections, and the means of making these are increasing by the reception of foreign journals." In those days of limited and uncertain communication a digest of information gathered from widespread sources was a boon, provided the material selected was of high standard, and it was fortunate that the editor was qualified to make the choice necessary to meet the needs of his readers.

The early issues were, therefore, eclectic in their content. The readers found in its pages contributions from the leading scientists and engineers in Europe, to which continent Americans still turned for guidance in the arts and sciences. These articles were not original in the sense that they had been prepared for publication in the JOURNAL but were abstracted from other periodicals, and each was accompanied by an acknowledgment of the source from which they were drawn. Many of these articles were especially translated for the JOURNAL, and were presented to American readers for the first time through its medium. However, the Institute was making progress in its own way, its reputation was spreading rapidly. In the sixth annual report (1830) of the Board of Managers it was said of the JOURNAL that "considerable exertions have been made by the editor and the publishing committee, to render it a more original work but, as yet, they have met with but partial success; nor can they hope completely to affect their object without a more general co-operation of members of the Institute."

The required co-operation came only slowly at first, since the members were concentrating upon instruction of a more or less elementary nature but, as the lecturers gathered confidence and they began to deal with more advanced material, the substance of the lectures became an integral part of the JOURNAL's contents. Articles headed "For the Journal of the Franklin Institute" to indicate their originality became commoner, and by the time the middle of the century was reached external matter had been largely abandoned, the columns were filled with original articles and reports of the committees. As much of this material reached a high standard, the JOURNAL gained additional repute for the Institute, both at home and abroad. It placed the Institute on terms of active fellowship with leading scientific societies throughout the world. By its exchange for the publications of those other societies, the Institute library has been enriched with a progressively expanding reservoir of knowledge.

In succession to Dr. Jones, the editorial functions have been discharged by Alexander Dallas Bache, Charles B. Trego, Professor John F. Fraser, Dr. Henry Morton, Dr. William H. Wahl, Professor George F.

Barker, and Robert Briggs. After 1878 supervision of the publication passed into the hands of the Committee on Publications with the editorial assistance of the Institute Secretary. As usually happens when work of this nature falls to a committee, most of the work descended upon an individual, and in this case the burden fell upon the secretary.

The historian of technology will find a rich mine of information in the pages of the JOURNAL. It is no exaggeration to say that the progress and development of American industry is reflected in its volumes. The growth of canals, railroads, shipping, lighting and illumination, mining, the metal industries and similar activities were all followed with intelligent interest. The reader will learn that the men of those pioneer days of American industry realized that experience is only true and valuable so far as it is on an extended basis, and that it is not true or valuable when local or partial. In order to secure as many facts as possible they were interested in failures as well as successes, and by carefully investigating the causes of the failures they were able to furnish remedies. This was the technique of an age symbolized by an absence of theories. A reader can follow the development of measurement in these pages, that feature which, more than any other, contributed to the suppression of cut and try methods and the substitution of more accurate and precise means based upon formulae, the results of which could be foreseen.

Many famous names are to be found in the indexes of the early volumes but, as we have stated, these were associated with articles which had been published originally in other periodicals. When the JOURNAL ceased to be eclectic and had succeeded in attracting a sufficient number of articles to be self-sustaining, there was no lowering of the high standard of the material furnished by its contributors. The best known names in science and industry are found just as frequently in the later volumes, but they were then attached to articles written especially for the JOURNAL.

Several noteworthy books have appeared in serial form in the JOURNAL. The earliest of these was Dr. L. Turnbull's *Electro-Magnetic Telegraph*, published in 1853. The articles which made up this volume furnished the best history of the telegraph published to that time, and remains as an excellent source for information upon the early stages of telegraphy. Other notable volumes which were first printed in the pages of the JOURNAL were W. J. Humphreys' *Physics of the Air* and Sir J. J. Thomson's *Electron in Chemistry*.

The Institute had been founded at a time when the whole scientific field was still so narrowly circumscribed that it was not beyond the comprehension of a single brain. Specialization had not yet been found necessary. But the growth of science during the ensuing fifty years was so rapid that it passed beyond the grasp of the individual mind.

The technology which sprang from the enlarged sciences required the cultivation of individual skills at the expense of those who had practiced handicrafts in many lines. When specialists began to form themselves into groups and societies to meet the new conditions, the Institute encouraged the movement and the pages of the JOURNAL were generously thrown open to give accounts of their proceedings. Its own members were active in the organization of such groups as the American Society of Civil Engineers and the American Institute of Electrical Engineers. The early meetings of the Engineers' Club of Philadelphia were also reported in the JOURNAL.

With the spread of specialization there has grown up a vast periodical literature to cover current needs. This has, to some extent, relieved the JOURNAL of much pressure on its pages. Since the members of the Institute are not drawn from any one field, the JOURNAL has remained as an appropriate vehicle for the publication of articles which have a wide range of application, especially in the nature of mathematical methods. While the subjects treated are likely to appeal to specialists in several fields, the articles are unlikely to meet with a welcome in any periodical devoted to limited fields of study. The JOURNAL, therefore, retains the character with which it first started, "to diffuse information on every subject connected with useful arts." The principal difference between the earliest and the latest issues is visible in the outlook of the contributors. In the beginning that which was published was in the nature of a record of what had already been accomplished. The readers were learners. Today, contributors keep a lively eye on the future and their work is frequently of the nature that foreshadows ultimate development. They seem to be aware that the future does not lie in other hands but in ours, to make of it what we can, and to shape it as we may.

SCIENCE . . . AND TOMORROW

A Symposium

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ASTRONOMY

BY

OTTO STRUVE

University of California

The commemorative issue of the JOURNAL of THE FRANKLIN INSTITUTE is intended to "predict future developments in science and technology based upon the considered opinions of today's leading authorities." In the words of the general editor, it "will be a composite picture of what can reasonably be expected in the basic physical sciences. . . ." It occurred to me that it would be of interest to construct a composite picture of our hopes and our aims—as the photographer builds up, by superimposing successive prints, a composite portrait of a specific group of persons, and thereby brings out the characteristic features of the entire group, and not of any one individual.

In order to learn what the astronomers of today believe may happen in their sphere of interests during the next few years, I mailed a circular letter to a number of well-qualified astronomers and asked them to send me their ideas concerning "the things to come." I have received replies from fifty-five persons which I have summarized and edited. Despite the obvious difficulty of making predictions in science, and the wide variety of special interests represented in this survey, there is a remarkable unanimity with regard to some of the problems that now confront us. But perhaps the best way is to start at once with the replies.

Most astronomers recognize that it is difficult to make long-range predictions and that unexpected developments may change the course of science almost over night. "The task of foreseeing the future of a science is very difficult: an unexpected discovery may entirely redirect the current of scientific activity. This is especially so in theoretical work" (**9**).[1] "The research problems confronting astronomy today are those being carried out currently by the active astronomers. . . . The *urgent* problems are presumably those being worked on today by the *best* astronomers. To attempt to predict the outcome of the current struggles with nature would be less profitable than to predict the outcome of a war just started—a war has usually only one of two endings, while the history of science shows that research may lead to almost any unexpected turn. Only in *retrospect* does science show the continuity we all know must exist" (**25**). "The history of science teaches us that major developments come almost always from the neglected fields.

[1] Boldface numbers in parentheses refer to the astronomers, listed at the end of the paper, who replied to Dr. Struve's letter.

Who, for example, would have spoken about Faraday's experiments on induction or Kirchhoff's in spectroscopy as 'urgent problems' in those remote days when they were performed? Faraday and Kirchhoff, themselves, probably did not know how extremely urgent these problems really were" (24).

"It is astonishing how many discoveries have been made by sheer accident. Roemer wanted to use the satellites of Jupiter for navigational purposes and found the velocity of light, Herschel wanted to measure the relative parallax of stars near to each other and found orbital motion, Hartmann wanted to determine the spectroscopic orbit of δ Orionis and found the fixed K line from extinction by interstellar matter, Bradley observed the positions of stars and found the aberration, Schwarzschild made a photographic light curve of Eta Aquilae and found its variation in color, the photographic range being larger than the visual one. You may add more recent discoveries, e.g., the polarization of the light of remote stars. Common to all these discoveries is that they were made by men doing something and interpreting their results properly. Of course, you prefer to plan observations, which will certainly be good for something, but it is hard to say, if that something will prove to be the most important.

"We are indebted to our ancestors for the treasure of observations they left us and from which they themselves only had a limited profit. The only way in which we can pay that debt is to provide future astronomers with the best possible observations" (17).

It is, of course, possible that some of us might, even now, recognize the great significance of an incipient development in a "neglected field," but this inquiry does not clearly bring out any such tendency. "The very best advances come in ways no one could anticipate long beforehand—for instance, the applications of nuclear physics to the source of stellar energy, or, longer ago, the whole of relativity" (39). Hence, we must be content with surveying "the application of perfectly well-known methods"—where there are "many fields in which we can see the desirability of change and of thorough investigation of all possibilities" (39). It is probable that these "simple, well defined, physical problems—problems which in themselves are seldom of tremendous importance, but the solution of which gives us satisfaction" (46), may even now contain the seeds of the great advances which we cannot yet discern but which are sure to come.

As one senior astronomer commented, "the field in which the least progress has been made in our time is without doubt fundamental positional astronomy" (39). He goes on as follows: "Apart from the transit micrometer and the zenith tube, we have made little progress since Airy's day. Many years ago H. H. Turner discussed tentatively the possibility of new fundamental methods, but the only actual attempt was one by Donner who photographed the region of the pole with a

fixed telescope—determining the pole as the center of a long diurnal arc of short exposures. His instrument (an astrographic refractor) was ridiculously deficient in stability. I believe that great gains in accuracy might be made with a specially constructed underground photographic telescope, fixed rigidly in a large concrete block (better solid metal, if not too costly) which had its levels determined by tubes running E–W and N–S, half full of mercury, and read by micrometers at the ends like Michelson's tidal observations; and its azimuth measured by another horizontal telescope fixed in the block and looking at a mire at the end of a long tunnel. All this stuff would be in an underground vault of constant temperature, and look out at the northern sky through a plate glass window.

"Observations made over 19 years would give an independent fundamental determination of nutation and one of aberration, if seasonal changes of temperature did not interfere; and also a very fine polar catalogue. If both poles were located in this way, points on the equator might be fixed 90° from each other, as suggested in Turner's forgotten paper; but here the refraction comes in with full force. The polar observations alone would be worth while."

There has never really been an interruption in the efforts of positional astronomers to determine more accurately the fundamental astronomical constants: the parallax of the sun, the constants of precession and nutation, aberration, etc. But during the past twenty-five years these tasks were eclipsed by the more exciting problems that arose through the advances in spectroscopy, photoelectric photometry, radio-astronomy and, above all, through the stimulation of theoretical astrophysics.

There is now in evidence a return to these positional tasks: "there is a tremendous need for continuous fundamental observations with meridian and zenith instruments" (49), in order to "improve the fundamental system of star positions—including investigations of positions and proper motions, as well as of the basic constants of spherical astronomy" (20).

It is clear that the easily available material on the proper motions of the stars has been more or less exhausted; yet the problem of stellar motions has become even more intricate and exciting than it was twenty-five years ago when Oort found the effect of galactic rotation. Present indications are that "the discussion of Edmondson's stars has revealed a marked dependence of the solar motion on the distance of the stars from the galactic plane—an effect which is confirmed when the motions of K-type giants with large inclinations of their galactic orbits are compared with stars having small inclinations" (49). In order to explain these, and other, discrepancies, it is proposed that Shane's Lick Observatory survey, which aims at the determination of star motions with reference to the extragalactic systems be completed and extended to the southern hemisphere (39, 49). There is also pressing need for

continuous fundamental observations of the sun, moon, planets, and standard stars, in both hemispheres (34), and preferably with improved meridian circles (50).

All of these problems are intended, in one way or another, to elucidate the kinematics of the stellar system: "a very urgent problem is the further verification of the general theory of relativity by means of the planetary motions. The results by Clemence show that they are contingent upon the precession. Although there are other approaches, the precession is found from the proper motions, provided we have a theory of the stellar velocities" (40).

In the solar system one expert is "impressed with the failure of any consistent gravitational theory to represent the observed motion of any body within the errors of observation. From the practical side, most of the existing theories will hardly suffice, even for navigational purposes, during the remainder of this century" (10). This will perhaps be a surprise to those who have thought that the motions in the solar system were, with the exception of the advance of the perihelion of Mercury, entirely accounted for by the existing theories (27).

This revival of interest in the classical problems of the solar system is particularly emphasized by the insistence with which astronomers press for accurate observations of the principal planets, the minor planets, the satellites, and the comets (41, 3, 7, 11).

In astrophysics the interests of astronomers center around two main problems: the physical nature of the sun and the chemical composition of the stars, especially their atmospheres.

With regard to the sun, one astronomer states that he is "pretty certain that the next ten years will see a rapid advance in our knowledge of the sun and its effects upon the earth. These include the ionosphere, magnetic storms, aurora borealis, cosmic rays, radio noise from the sun, and even the weather" (30). Another envisions "a very large solar image of superb definition—at least 20 inches in diameter—and accompanied by steady seeing" (29). We can look forward to important discoveries with regard to the fine structure of the solar granules which is now believed to be the visible effect of turbulent motions in the sun's reversing layer (28, 36).

Nearly all astronomers interested in the problems of stellar physics in one way or another emphasize the importance of finding the exact amount of each chemical element in the atmospheres of the stars as well as in their interior regions. Ultimately these studies should permit us to solve the problem of the origin of the chemical elements (39, 20, 23, 18, 6, 45, 48, 31, 53, 15).

The idea is not new. Probably all astronomical spectroscopists since the days of Fraunhofer have worked towards its solution. But every time their hopes were aroused, some new discovery would come along and introduce new complications which had to be removed first.

The simple visual differences in the spectra of "helium stars," "hydrogen stars," and "metallic-line stars" turned out to be differences of temperature and pressure—not differences of composition. More recently, differences in the line intensities of any single element observed in two stars having identical temperatures and pressures, turned out to be the result of differences in the degree of agitation or "windiness" in their atmospheres. Only quite recently have we overcome all obstacles and a few accurate determinations of chemical abundances are now available. But these refer only to what we might call "normal" stars, and they are remarkable especially by their similarity. Yet, we know that differences in the composition of stellar atmospheres really exist and we must concentrate upon them in order to learn whether nuclear transformations—or some less spectacular mechanism, such as selective radiation pressure—can explain them.

By a fortunate coincidence the theoretical astrophysicists have almost at the same time succeeded in overcoming the difficulties which confronted them when they attempted to use the ordinary physical laws of gases—their absorbing properties, pressure-volume-temperature relation, etc.—to build up an imaginary star that would turn out to have the correct mass, radius and luminosity. One of the quantities that must be properly adjusted is the mean molecular weight of the stellar material. If it is similar to that of ionized hydrogen, the star contains a large amount of hydrogen in its interior, but if it departs markedly from this value, the presence of the heavier elements can be ascertained from the manner in which their many free electrons of small weight—in the highly ionized state they are in—combine with the heavy nuclei to produce the best fit for the mean molecular weight.

At present there is no reason to believe that there are significant differences in the composition of the atmospheres and stellar interiors. But we are by no means certain that this will be always the result of the two types of investigation. It is possible, even probable, that mixing is a slow process in some stars, and hydrogen may well be all converted into helium in the interior regions of a very old star, even though we observe its presence in the outermost layers, where the temperature is too low for nuclear processes to play a role.

In order to advance our knowledge of the chemical composition of the stars, many astronomers intend to refine still further the theory that teaches us how the light and the heat generated deep inside the stars are converted by the outer layers into the kind of radiation that emerges outward and finally reaches the terrestrial observer. For example, it is still necessary to improve our knowledge of the continuous light of the stars (8, 2); and in order to do so with the utmost efficiency it is desirable that our knowledge be increased toward shorter wave-lengths by means of rockets and toward longer wave-lengths by means of radiometers of different kinds and even of radio telescopes (24, 54).

An entirely new field of astronomical observing was opened by the development of the radio engineers' procedure: "A large mirror, perhaps 200 feet in diameter, should be located near the equator of the earth in order that most of the sky may be observed. It should be placed upon a high mountain on an island in the middle of the sea in order that the surface of the water may be used as a mirror. A type of interferometer (previously applied on a smaller scale in Australia and elsewhere) is thus possible. As the object rises from the sea and later sets into the sea a very precise determination may be obtained of its position in the sky. By this means the great disadvantage of extremely long wavelengths may be overcome, and the resolving power of the instrument may be made to resemble that of optical telescopes" (37).

It is already known from the work of the radio astronomers in several countries that there are distinct sources in the sky which emit radio waves at a very great rate. The exact identification of these so-called radio stars is not yet certain and future work will undoubtedly be concerned with their identification (37, 48, 28, 45, 22, 5, 43).

The greatest number of astronomers urged that work be done to explain the evolution of the stars, and to a somewhat lesser extent the origin and evolution of the solar system (5, 43, 32, 1, 52, 45, 12, 21, 6, 42, 28, 22).

The problem of the origin of the stars and their later history has received a great impetus from the work of Baade and others on the populations of different parts of our Milky Way galaxy, as well as of the neighboring large galaxies, the Andromeda nebula, the Magellanic clouds, etc. We know that stars in spiral arms are usually rich in hydrogen; many of them are hot, and their physical characteristics are best described in terms of the classical Hertzsprung-Russell diagram and the mass luminosity relation. But there are in our part of the Milky Way a few stars that presumably originated in the deepest, most centrally located regions and may have accidentally been perturbed in their motions to such an extent as to reach that remote region of a spiral arm in which the sun is located. These interlopers possess altogether different physical properties from the "native" inhabitants of our spiral arm. Perhaps they are deficient in hydrogen (though some very recent work disputes this), and the suspicion arises that they may have exhausted their available supply of hydrogen through the nuclear conversion into helium.

"Many examples of significant problems that we can ask in regard to stellar populations come to mind. Is there a strict division of stars into *two* populations, or are there many populations, or are there all kinds of intergrades of populations? How are these populations or mixtures of populations distributed throughout the galaxy? Are there variations in the physical characteristics in a given type of star with position in the galaxy? How, for instance, does the distribution of periods of the

long-period variables, the RR Lyrae stars, the classical Cepheids, the W Virginis stars, and so forth, vary with height above the galactic plane and with distance from the galactic center? What is the relationship between the interstellar medium and the stellar population type? Spectroscopically, what are some of the distinguishing characteristics of stars of different populations? These are, of course, only a few of the questions that can be asked; they are, in one sense, only superficial, for eventually one will wish to know the reasons for the answers given to these questions. The particular questions suggested, however, are some of those for which we are now in a position to give some answers through statistical studies of stellar motions, through studies of magnitudes, colors, and spectra of stars, galactic and globular clusters, and through spectroscopic studies of selected stars. With large telescopes one can learn much through study of members of the local group of extragalactic nebulae" (52).

It is understandable that astronomers intend to clarify the nature of the spiral structure of our Milky Way (47), that they invoke all means to measure the distinction between the two stellar populations, using double stars for this purpose (21) or the masses of different types of stars (50), or the extremely profitable study of the intrinsic variables, some groups of which conspicuously belong to the spiral arm type of population, while other variables equally clearly belong to the galactic nucleus type of population.

This problem is intimately connected with the problem of the chemical composition and the origin of the chemical elements. It raises the question whether the supernovae, the ordinary novae, the relatively inconspicuous explosions of the U Geminorum stars, and the extended envelopes, may not all represent catastrophic forms of nuclear processes in the stellar interiors (13, 31). It also raises the question whether the interstellar gas and dust may not represent the debris of such stellar explosions and perhaps of other, less catastrophic forms of dispersal of the stellar material. At the same time we more and more often are led back to the early ideas of Kant, according to which the stars originate through the condensation of interstellar gas and dust (39, 42, 43). Perhaps there is a continuous process of star formation out of interstellar matter and a corresponding replenishment of the matter through the disintegration of stars which somehow have lost their stability.

Two important physical theories have recently entered the domain of astrophysics, and their further exploration promises to yield results of considerable significance. The first is the study of random motions of finite elements in a gas, which is described as turbulence; the other is the study of electromagnetic forces in the stars and in the interstellar medium. It was known almost fifty years ago that the sun is a relatively weak magnet, but it has only recently been found that there are stars which possess enormously powerful magnetic fields. It was also

noticed, a few years ago, that the particles in interstellar space often align themselves in some preferential direction which bears a direct relation to the plane of the Milky Way. Such a tendency can only be explained if we assume that the interstellar clouds possess magnetic properties (9, 21, 12, 42, 15, 43, 23, 4).

In theoretical astrophysics "the combination of hydrodynamics and electromagnetism is likely to achieve the solution of many problems which have hitherto remained obscure. . . . Electromagnetic forces will have to be increasingly invoked for interpreting many phenomena related to the structure of stars, stellar atmospheres, and interstellar clouds. But the theoretical problems involved are exceptionally difficult, and a single fortunate idea may set the whole train of developments going, in the same way as the idea of radiative equilibrium set the pattern of theoretical astrophysics of the past 40 years" (9).

The completion of the 200-inch telescope on Mount Palomar will undoubtedly aid in the solution of all these numerous problems, but it is also expected to answer an even more important question, namely, that of the red shifts of the extragalactic systems, which form the basis of the theory of the expanding universe. Nearly all astronomers anticipate great developments in this field. Some emphasize the "geographical and kinematical distribution" of different types of stars and gaseous nebulae in our own galaxy and in other neighboring systems" (55). Others recommend careful but time-consuming studies of the velocities, brightnesses, and colors of all extragalactic systems within the reach of the 200-inch telescope (14, 44, 39, 12, 26). Still others discuss the masses of the extragalactic systems, for example, by means of their gravitational action upon each other in binary systems or clusters of nebulae (53); but all expect the most significant results from the direct study of the red shift (13, 33, 45, 21, 41, 31, 4, 20).

These are, essentially, the directions in which the astronomers of today believe their science will develop. As I indicated in the beginning, there are not now in evidence any spectacularly new ideas or methods. Only three major new instrumental developments are recommended—one in radio astronomy, another in solar research and the third in fundamental astronomy of position. Undoubtedly, most astronomers feel that the 200-inch telescope will so greatly advance astronomy that it would be unwise to plan other large instruments of the conventional design in the northern hemisphere. But nearly one-half of the replies urge that more effort be made in the southern hemisphere, and one person writes: "One of the major problems of American astronomy is to adequately staff and instrument southern hemisphere observatories. Four American universities run three South African observatories with a grand total of four professional astronomers. For the price of a medium-sized Schmidt telescope fifty American astronomers and their families could be transported to South Africa, and

returned to the United States, allowing for transportation and extra personal expenses incurred in such a trip" (19).

Although the astronomers are unexpectedly modest in their recommendations for new telescopes—probably for the first time in history no one wishes to build "the largest telescope in the world"—they show an equally startling unanimity in predicting "that the boundaries between astronomy, geophysics, physics, electronics, and a lot of the border line sciences will be even further broken down" (30). Apparently, most of us agree that we represent a branch of general physics, that our aims and those of the physicists are the same, and that a distinction, if necessary at all, should be based only upon technical differences of instrumentation.

Perhaps our greatest advance will be made in those relatively popular fields of study which most astronomers agree upon. But it is just conceivable that the clue to future developments will be found in some of the more unusual suggestions that have come to me. Among them the most interesting is the idea of a projectile to the moon (32) and the revival of the old interest in the canals of Mars (36).

Some of my correspondents did not confine themselves to scientific questions. Many expressed concern over the manner in which research in astronomy is to be financed in the future. This reflects the growing recognition that very large enterprises such as the construction of the 200-inch telescopes are hampered by the general economic and political uncertainty of our time and that large cooperative undertakings, like the Carte du Ciel are ruled out for the present. One distinguished astronomer lists as the most urgent problem confronting astronomy the "continued peace without which astronomy has no future and a weakened present" (41). And another draws attention to the need for "more income for astronomers." In his opinion more and better results in science can only be expected if astronomers are paid enough to remove or reduce their concern with economic questions (38).

REFERENCES

(1) Harold L. Alden, Leander McCormick Observatory.
(2) Lawrence H. Aller, University of Michigan.
(3) Dinsmore Alter, Griffith Observatory and Planetarium.
(4) Horace W. Babcock, Mount Wilson and Palomar Observatories.
(5) C. S. Beals, Dominion Observatory, Ottawa.
(6) William P. Bidelman, Yerkes Observatory.
(7) Dirk Brouwer, Yale University Observatory.
(8) D. Chalonge, Institut d'Astrophysique, Paris.
(9) S. Chandrasekhar, Yerkes Observatory.
(10) Gerald M. Clemence, U. S. Naval Observatory.
(11) L. E. Cunningham, University of California, Berkeley.
(12) A. J. Deutsch, Harvard College Observatory.
(13) G. Gamow, George Washington University.
(14) Cecilia Payne Gaposchkin, Harvard College Observatory.

(15) Jesse L. Greenstein, Mount Wilson and Palomar Observatories.
(16) John S. Hall, U. S. Naval Observatory.
(17) E. Hertzsprung, Toelloese, Denmark.
(18) J. Allen Hynek, Ohio State University.
(19) John B. Irwin, Kirkwood Observatory.
(20) Hamilton M. Jeffers, Lick Observatory.
(21) Alfred H. Joy, Mount Wilson and Palomar Observatories.
(22) Philip C. Keenan, Perkins Observatory.
(23) K. O. Kiepenheuer, Yerkes Observatory.
(24) V. Kourganoff, Institut d'Astrophysique, Paris.
(25) Gerard P. Kuiper, Yerkes Observatory.
(26) F. C. Leonard, University of California, Los Angeles.
(27) A. O. Leuschner, University of California, Berkeley.
(28) Dean B. McLaughlin, University of Michigan Observatory.
(29) R. S. McMath, McMath-Hulbert Observatory.
(30) Donald H. Menzel, Harvard College Observatory.
(31) Paul W. Merrill, Mount Wilson and Palomar Observatories.
(32) M. Minnaert, Astronomical Observatory, Utrecht, Netherlands.
(33) O. Mohler, McMath-Hulbert Observatory.
(34) H. R. Morgan, U. S. Naval Observatory.
(35) W. W. Morgan, Yerkes Observatory.
(36) Edison Pettit, Mount Wilson and Palomar Observatories.
(37) Grote Reber, National Bureau of Standards.
(38) R. S. Richardson, Mount Wilson and Palomar Observatories.
(39) Henry Norris Russell, Princeton University Observatory.
(40) Jan Schilt, Rutherford Observatory.
(41) Harlow Shapley, Harvard College Observatory.
(42) Charlotte and Bancroft Sitterly, National Bureau of Standards and American University.
(43) Lyman Spitzer, Jr., Princeton University Observatory.
(44) Joel Stebbins, Lick Observatory.
(45) K. A. Strand, Dearborn Observatory.
(46) P. Swings, Institut d'Astrophysique, Liege, Belgium.
(47) R. J. Trumpler, University of California, Berkeley.
(48) A. Unsöld, Institut für Theoretische Physik, Kiel, Germany.
(49) A. N. Vyssotsky, Leander McCormick Observatory.
(50) N. E. Wagman, Allegheny Observatory.
(51) C. B. Watts, U. S. Naval Observatory.
(52) Harold Weaver, Lick Observatory.
(53) Olin C. Wilson, Mount Wilson and Palomar Observatories.
(54) Bradshaw Wood, Flower Observatory.
(55) F. Zwicky, Mount Wilson and Palomar Observatories.

CHEMISTRY IN THE TWENTIETH CENTURY

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In 1900 the science of chemistry was almost in a primitive state as compared with its position in 1950. The 19th Century began with the enunciation of the atomic theory by Dalton, and in that century chemists succeeded in establishing the basis of atomic weight determination and the molecular weight of molecules. They first synthesized characteristic organic compounds. The theory of valence was discovered by Frankland and developed during the rest of the century. Kekulé enunciated the four valency of carbon, and that very simple idea has served as a fundamental guide to organic chemistry ever since. The first and second laws of thermodynamics were discovered and Gibbs published his papers on chemical thermodynamics, and his work on this subject has remained almost unchanged to the present time with the exception of the discovery of the third law of thermodynamics. Gibbs also enunciated the principles of statistical mechanics. Boltzman and Maxwell had established the fundamentals of the kinetic theory of gases. Many preparative procedures had been developed, and the first years of the century marked the discovery of the Grignard reagent and the catalytic procedures of Sabatier. The procedures of inorganic analysis were well understood. A chemist of 1900 would have felt that the numerous data of the science were very extensive indeed, though today we regard them as completely inadequate. It is with this background that we must turn to the history of chemistry during the first 50 years of the 20th Century.

Certain fields of chemistry during these 50 years have been markedly influenced by a number of very important ideas and discoveries which originated in the closing years of the 19th Century or the first years of this, but other great fields of the science have made progress by the addition of much less dominating ideas which altogether make an imposing contribution to the science at this time.

THE QUANTUM THEORY

The quantum theory was enunciated by Planck in 1899, and it has had a more important effect upon the physical sciences than any other idea that has been proposed in the last 50 years. It has not only influenced physics, but it has also influenced chemistry equally profoundly, and in fact has led to the understanding in principle of all

chemical phenomena. The quantum theory was proposed by Planck in his attempts to explain the black body radiation law. If the ether were a continuous solid, it should vibrate with an infinite number of degrees of freedom and the equal partition laws would require that each of these degrees of freedom should contain energy. In fact, the radiation laws predict what is known as the violet catastrophe, namely, that all of the energy of black body radiation would reside in the highest frequencies. This conclusion is obviously contrary to experience, since the experimental facts in regard to the distribution of frequencies in black body radiation show that there is small energy in the low frequencies, that the energy rises to a maximum as the frequency increases, and then decreases again to zero at the infinite frequency. Planck suggested that the different possible modes of vibration in a Hohlraun could acquire energy only in multiples of a fundamental unit, $h\nu$, where h is Planck's constant and ν is the frequency of the radiation. Thus, discontinuity in the amounts of light energy which could be acquired in the different degrees of freedom was introduced. Shortly following this, Einstein showed that the facts of photoelectricity phenomena could be explained on the assumption of particles of light having energies equal to $h\nu$. Shortly following this, the explanation of the heat capacities of solids was given by Einstein and Debye on the basis of the quantum theory. Heat capacities will always decrease from the values required by the equal partition of energy as the temperature approaches absolute zero, and it is the discrete energy levels again that are responsible for this. In 1913 Niels Bohr proposed his atomic theory. It made use on the one hand of the Rutherford nuclear atom and on the other of the quantum theory of Planck. Though it was semi-classical in character, it again introduced the discontinuity of energy states. This theory was developed during the second and third decades of this century and led to the enunciation of the present quantum mechanics, and the indeterminancy principle which states that it is impossible in principle to determine with infinite precision both positional and momentum coordinates of a system. The periodic system discovered in the preceding century has been completely explained by the aid of this theory, and this explanation had arrived by the middle 1920's. Thus the most important empirical classification of the elements was completely explained by the applications of this theory.

The century opened with what might be called the toothpick theory of valence, not because our scientists believed that there was anything like the small pegs that were used to make molecular models, but because the persistent use of such models and corresponding diagrams led us all to think more or less in terms of such a simplified model. The explanation of valence awaited the full development of the quantum mechanical theory, and has led in the hands of Heitler, Mulliken,

Pauling, and others, to an elucidation of nearly all valence problems in terms of the quantum theory and the quantum mechanics. This problem of course involves a many body problem of mechanics which is not simplified in the slightest by the use of quantum mechanics. The exact solution of the quantum mechanical formulae for the valence problem is of course impossible, and only approximations to the solution of the problem can be given. But these approximations have enabled us to understand many of the problems of valence, resonance phenomena, the appearance of color in organic compounds, the symmetry of molecules of various kinds, and the origin of forces between molecules in the gaseous, liquid and solid states. The complexity of the calculations still requires that we shall depend on experimental facts for exact data.

The hydrogen atom is the only atomic system for which exact formulae for its energy states can be given, and of course this contributes in itself nothing to the science of chemistry, since chemistry involves the transformation of one or more substances into another substance or other substances, and one must have for the understanding of chemistry a description of both the initial and final substances, and in order to understand the transformation processes we should have an understanding of all the intermediate stages for the transformation. Thus an understanding of the hydrogen atom helps us but little. The simplest molecule which we have is the hydrogen molecular ion, consisting of two protons and one electron. It is already a three-body problem for which exact solutions are difficult to secure. The hydrogen molecule is the simplest molecule of chemistry, but it already is a four-body problem, or a two-body problem if we make the approximation that the protons are stationary, and the solution of the quantum mechanical problem is very difficult indeed and cannot be made precisely except with great effort. For more complicated molecules exact calculations of energy states are even more difficult.

The third law of thermodynamics was discovered by Nernst and its complete verification has been established during this century. The entropy of a substance becomes zero at the absolute zero of temperature provided it is brought to this temperature by a reversible process. The explanation of this law is given by the quantum theory and statistical mechanics. Complete order within a material body exists at the absolute zero of temperature provided the substance is brought to this temperature so slowly that equilibrium exists at all times.

Thus the most important concept for the science of chemistry has been and is the quantum theory of Max Planck.

THE PROPERTIES OF INDIVIDUAL ATOMS AND MOLECULES

The exactness of chemical knowledge depends to a large degree on the determination of the sizes, masses and numbers of atoms and molecules, and these were all unknown at the beginning of this century.

The determination of the charge on the electron by Milliken and the careful determination of the value of the Faraday of electricity furnished the value of the Avogadro number and thus the values of these quantities. Immediately detailed descriptions of chemical phenomena were possible. The discovery of X-rays by Roentgen gave a means of investigating the arrangement of atoms in crystals and later of atoms in liquids and gaseous substances. This light of short wavelength might have determined the Avogadro number for it determined the arrangement of atoms in crystals, and if the wavelengths had been determined by gratings as they were later, the exact distances would also have become known. These measurements confirmed the values previously determined from the charge on the electron.

By these new tools all the ideas in regard to the spacial arrangement of atoms in molecules and in solids developed from the theories of valence of Frankland and Werner could be investigated and placed on a secure basis.

RADIOACTIVITY

The third great discovery of the closing years of the 19th Century was that of radioactivity by Becquerel and Pierre and Marie Curie. During the early years of the century the discovery and systematization of the varieties of radioactive substances were carried on by Marie Curie and also by Rutherford, as well as others. Rutherford also used the alpha particles to demonstrate the existence of the nuclear atom which has such a fundamental importance in connection with the whole study of the structure of atoms. The subject, however, moved rather slowly until the end of the 1920's, when the great mass of physicists who were interested in the electronic structures of the atom turned to the problems of radioactivity and high energy generally. This is an important development in the field of physics, but it had its reflection in important studies in the field of chemistry. This led to the discovery of, first, radioactive isotopes, and then the stable ones, and with it an understanding of the atomic weights of the elements. It explained the nearly whole number characteristic of many of the atomic weights of the lower part of the periodic system and the definitely fractional ones that had puzzled workers on atomic weights for many years. The artificial radioactivity opened up vast fields of investigation for chemists, for this subject has been conventionally classified as chemistry by some and as physics by others. At present the interest in this field centers along two lines: one, the understanding of nuclear structure and the systematization of the nuclei of atoms, which is the most natural extension of the chemistry of the 19th Century; and two, the use of these "nuclides," as they are called, in tracer studies for the more conventional type of chemistry and in particular in the field of biochemistry.

The most startling discovery since the original discovery of radioactivity was undoubtedly the discovery of fission by Otto Hahn in 1938,

which led to the spontaneous release of nuclear energy. This discovery has made possible the production of radioactive substances in large quantities, but also led to the first production of an element on a large scale, namely, plutonium, and it has led to the synthesis of a number of elements that were not present in nature in appreciable quantities. This and the various types of high energy apparatus, notably the cyclotron, have enabled us to fill in the periodic system of the elements out to number 98 by the addition of artificially produced elements of atomic numbers 43, 61, and 85, and the extension of the periodic table beyond atomic number 92 to 98. The elements of the actinide series of rare earths proved to have interesting analogies to the rare earths of the lanthanide series, though their chemistry is different in very interesting ways.

ORGANIC CHEMISTRY AND LIFE PROCESSES

Turning to the field of organic chemistry, we find that there is a notable lack of such dramatic points as those which have stimulated so much of physical chemistry during this century. The chemistry of the carbon atom appears to have an infinite complexity. We find that we can still add new and unusual types of chemical reactions and it is possible to go on to the study of larger and more complex molecules. The chemistry of carbon is interesting because of its great importance in living organisms, and much of the driving interest of organic chemistry comes from this fact, either in the investigation of natural substances that owe their existence to the activity of living organisms, or in the processes taking place in such organisms. At the turn of the century little was known in regard to either the substances existing in organic matter or these processes. Emil Fischer investigated the sugars and the proteins and correctly elucidated the essential building blocks of these substances. These studies have been continued by others in this century until today we have at least the beginning of an understanding of the chemical substances that make up most of the material of living organisms. This work was followed by the discovery of the vitamins and the study of the action of enzymes. It has become increasingly evident that very small amounts of materials from the point of view of the weight fraction are of dominating importance in the living process. Due to Loeb and Warburg particularly the essential similarity of the chemical processes of living organisms has become evident. Today we investigate reactions which were discovered by living organisms before the Cambrian period of geological history began.

The importance of tracers in connection with such studies cannot be over-emphasized, for living organisms only exhibit their characteristic properties in a great mixture of substances and in the simultaneous progress of many chemical reactions. One has a living organism only in a condition of great impurity of organic and inorganic substances,

and if one is to study living processes they must be studied in the impure state. This is a condition that is foreign to most of the work that has been done in physical, organic and inorganic chemistry in the past. The adoption of tracer techniques first allows us to follow chemical reactions in the living organism without distorting or destroying the living process. This type of study was begun by Hevesy many years ago using the natural radioactive tracers. It was furthered substantially by Schoenheimer during the early 1930's when he applied heavy hydrogen particularly to living processes, thus introducing for the first time a vitally important tracer into the study of intermediary metabolism. It is being continued at present with the important radioactive tracer carbon-14 as well as many radioactive and stable tracers besides. It is to be expected that these studies will add one of the most important chapters in chemistry during the second half of the 20th Century.

FREE RADICALS

In 1900 Gomberg first showed that free radicals exist. He made the discovery by a study of the properties of ethane in which large organic radicals were substituted for the hydrogen atoms. These are the so-called "stable" radicals. This discovery was an organic curiosity for many years, until Paneth demonstrated that unstable free radicals existed as intermediates in many chemical reactions. This development has led to a complete rewriting of much of the mechanism of organic reactions, for it appears that practically all of them proceed through the formation of free radicals in the gaseous state, or on solid surfaces, or in the liquid state. Some free radicals exist for very short periods of time and others exist long enough to be demonstrated by special methods. Free radicals, which were in the case of Gomberg's study entirely compounds of trivalent carbon, are compounds in which the usual valencies used by the organic chemist are not satisfied, and include atomic hydrogen, methyl groups, the OH group, the NH_2 group, etc.

Chemical industry has made an important contribution to chemistry in this century by its extensive elucidation of the chemical reactions of the paraffins, a field of organic chemistry that was practically unknown at the beginning of the century and which today is the basis of a great deal of chemical industry and has shifted the whole source of chemical substances from plant or coal tar sources to petroleum. Many of the paraffin reactions also take place through the intermediacy of free radical mechanisms.

ELECTROLYTIC DISSOCIATION THEORY

There are a number of interesting fields of chemistry that do not fall under the prominent heads which have been given in this paper, and it is necessary to review these separately. In the closing years

of the 19th Century Arrhenius proposed the electrolytic dissociation theory in order to account for the striking properties of certain classes of solutions, those which conduct the electric current and show an abnormal lowering of the freezing point, elevation of the boiling point, etc., of water solutions. This theory is very nicely corroborated by X-ray studies on electrolytes, where we find in the solid state that the positively and negatively charged radicals are separated in the crystal lattice and appear as individual units in this lattice. Arrhenius' discussion of the subject was qualitative and led to a great deal of work on the electrolytic solutions, but it was obvious that the properties of such solutions could not be regarded as due to the effects of independent ions, positive and negative, in the solution, nor was it expected that they should be independent, for positively and negatively charged ions should attract each other or repel each other. This problem was attacked by mathematical chemists and physicists, and the first approximate solution of the problem was secured by Debye. The theory is limited to very dilute solutions, but the behavior of such very dilute solutions is approximately predicted by his theory. Extensions of these considerations have gone into the field of doubly charged ions, as for example the amino acids and their very striking properties, probably intimately related to the properties of these substances in connection with the living processes, and extensive studies of the polar moments of molecules in the gaseous and liquid states enable us to understand a great deal about the physical properties of such molecules. The kinetics of chemical reactions in solutions, which involve charged ions, was given an enormous impetus by the work of Bronsted. Here Bronsted showed in a logical way why at least many chemical reactions involving ions were influenced by the presence of the charges on the ions.

KINETICS OF REACTIONS

The kinetics of reactions has perhaps proceeded in one of the most unsatisfactory ways of any field of chemistry, especially chemical reactions taking place in the gaseous state. It is not that very interesting things have not been learned in regard to the velocity of chemical reactions, but the whole system of such chemical reactions is much too complex to have been welded, up to the present, into a really satisfactory system of concepts. So many of the gaseous reactions are heterogeneous on the walls of any vessel in which the gas can be confined, or else the individual intermediate processes are so numerous that it is difficult to investigate any one of them or any few of them separately. This field which was begun at the beginning of the century, particularly by Bodenstein, and about which many empirical data have been accumulated, will have to be continued during the course of the second half of this century if satisfactory elucidation is to result. The difficulty is again that of the many particle mechanical systems involved and no

exact theoretical solution can be expected; only approximations, the validity of which is always limited and for which the limitations of the validity cannot be estimated, are available.

The mechanisms of chemical reactions in the liquid state have made much more substantial progress. Lapworth in the early years of the century first stated the problems involved in organic reactions and Bronsted gave a very substantial orientation to the reactions of charged and uncharged molecules in electrolytic solutions. Their efforts have been continued by many others. However, much work remains to be done before we secure a well-systematized body of knowledge in this field.

ABUNDANCES OF THE ELEMENTS AND NUCLIDES

Chemists during the past and up until recent years have by and large studied pure substances or mixtures of a few compounds of pure substances. Deviations from this practice have occurred in the case of biochemistry, where the living processes must be studied in the presence of a vast mixture of chemical substances. There is another field in which this situation obtains, namely, that of chemistry in nature, including the inorganic substances. We live on a planet where many chemical reactions are taking place in nature, in the atmosphere, in the seas and in the crust of the earth, and on other planets and the stars. These reactions are uncontrolled in the way that most chemical reactions are controlled in the laboratory, but they are nevertheless predominantly chemical in character and of great interest. They are in fact the chemical changes analogous to the whole observational data of the astronomers. A few chemists have undertaken to understand this complex chemistry in nature. Among these Goldschmidt stands out as having done remarkable work in this particular field. He attempted to determine the abundance of the elements in nature and in the meteorites and to understand the chemical processes which segregate them in those parts of the earth's crust available to us and in the meteorites which fall on the earth, and has attempted to correlate these abundances with those in the stars. Until recently almost all of our information about the abundances of the elements on the earth and much of that about the abundance in the cosmos stems from this important work of Goldschmidt. The systematic investigations of the abundances of isotopes begun by Aston and continued by others since, together with the fundamental work of Goldschmidt, has made possible the classification of nuclei begun by Harkins and continued by many others.

LARGE MOLECULES

The study of large molecules has made steady progress during this century. The first substances of this class to be partially understood were the proteins and the carbohydrates. Resins have been known from prehistoric times but their synthesis has been accomplished in this

century, and this synthesis has been accomplished largely because of fundamental studies of the structure of large molecules. Also the understanding of the chemical properties of free radicals was essential. These studies open a fascinating new and complex field for the compounds of carbon.

During the years of this century there has been an important accumulation of chemical data. There is often a tendency to over-emphasize the importance of fundamental discoveries as compared with the steady and careful accumulation of scientific facts and numerical data. Without such a storehouse of facts our ideas in regard to the structure of matter and the chemical processes in particular would be as ineffective as those of the ancient Greeks. During this century the tables of physical constants have constantly and steadily grown in size until it is possible to turn to tables of this kind for the elucidation of many chemical problems. A further growth of such data is needed if we are to be able to make important advances in understanding the science in the future.

CONCLUSION AND THE FUTURE

In papers of this kind it is customary for the writer to presume to make predictions in regard to what the science may do in the future. One hardly credits any successful prophecies of this kind to anything more than a lucky accident. It is doubtful if any scientist of the year 1900 had more than the haziest notion in regard to the development of our science during the next 50 years. At that time the great importance of the quantum theory, of X-rays, of radioactivity, were appreciated by few people and probably those few would have found the extension of their ideas by 1950 to have been completely beyond anything they imagined. We must recognize that at the present time we stand with respect to the second 50 years of this century in exactly the same position as the scientists of the year 1900 stood relative to the past 50 years.

During the next 50 years there will be an adequate elucidation of the structure of the atomic nucleus, but most of this work will be classified as physics rather than chemistry. In this field we are studying a universe in which the energies are all enormously greater than those of the conventional chemical processes by many orders of magnitude. The processes that take place in this field would represent an interesting chemistry if temperatures of billions of degrees Kelvin, or higher, and high densities of material were available to us for observation and experimentation. It is obvious that we will reconstruct this chemistry only in thought, or observe its effects as the result of the explosions of super-novae or by penetrating in thought to the centers of the stars.

Another important field of advance during the coming century will be in the processes of living organisms. These processes appear to

have a complexity beyond anything that we can describe at the present time. The complexity of a protein molecule, or of an enzyme, is beyond our knowledge at present, and these by themselves are not living. The crystallization of large protein molecules by Stanley showed that there appears to be a continuous bridge between large molecules of the protein type and living organisms. Students of this subject are often pessimistic about the possibility of understanding the origin of life, but somewhere in the future, whether it is the remaining years of this century or years to follow, man will have an understanding of the origin of life. The studies made by Kuiper in recent years have demonstrated about as conclusively as we are likely to demonstrate for some time that life exists on Mars, probably of a simple plant variety. Of the planets in the solar system, only Mars and the earth have physical conditions making possible the existence of life of the kind that we include in that term and the only kind of which we have any knowledge at all. These two planets which have developed life show that life appears to be a regular phenomenon which will develop on any planet for which the conditions are appropriate. Since it is estimated that about one star in one thousand must be of approximately the type of our solar system, it is obvious that many planets are inhabited on the basis of this argument, and also it appears that life must come about as a result of the chemical reactions possible in the early history of such a planet as our own. Though the complexity of life seems to be so great, it nevertheless occurs, and it should be possible for man to understand how it appeared on earth. This will make an interesting study during the years to come, either of this century or others in the future.

Beyond these two suggestions, the present writer finds it impossible to speculate. It is obvious that present lines of endeavor will be continued and in this effort new and unexpected ideas will appear. Among the most interesting of discoveries will be the ones which we do not anticipate at all. These discoveries will furnish the great driving force in most cases for our science in the future. These will induce chemists to spend their lives elucidating the details of the great discoveries and it will enable them to build a greater unity into the science of chemistry and related subjects than exists at present.

TRENDS IN ANALYSIS

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1. INTRODUCTION

Analysis is the clearing house of mathematics. There are those who would say that analysis is primarily concerned with limiting processes. Such a characterization seems inadequate today when there is hardly a branch of mathematics that does not use limits of some sort. Algebra with its formal rules for operating is relatively easy to define. Geometry and, in particular, topology are less easy to define, and finally, analysis is almost impossible to characterize in its present state except by enumeration.

It will be impossible within the limitations of space and language proper for an account of this sort to give more than a profile of analysis. The relatively small number of fields in analysis to which reference will be made have not been selected on a basis of the numbers of workers in these fields. Rather it has been the inherent interest of a field, its nearness to a pioneer stage and its potentialities which have weighed most heavily with the writer. There are significant fields of mathematics such as topological groups and Lie groups which belong to algebra, topology, and analysis which are not discussed here because other fields (no more important) contain more of analysis proper as it has traditionally evolved.

Analysis as of today is characterized by the extensive use it makes of topology and algebra and by its free use of new abstractions. To understand the trend of mathematics one must understand the origin and use of abstractions. We dwell briefly on this point.

Sets of objects of any well-defined sort are often called *spaces*. The word space has no *à priori* connotation of distance or nearness unless specifically added. Objects in a space are conveniently called *points*. If p, q, r are points or objects in a space S there may be defined a number $d(p,r)$ called the *distance* between p and r. Its characteristic properties are those of ordinary distance. The number $d(p,r)$ shall be positive unless $p = r$ and in this case $d(p,p) = 0$. Most important is the so-called *triangle axiom*

$$d(p,r) \leqq d(p,q) + d(q,r). \tag{1.1}$$

The reader recognizes this relation as satisfied by any three points p, q, r in a plane. A space S with the above definition of distance is called an

abstract metric space. It is a typical abstraction. The space S may or may not contain elements which behave like straight lines, or like angles.

One of the advantages of modern mathematical abstractions is that they reduce relatively complicated systems, essentially by analogy, to simpler systems. Consider for example a space S consisting of all closed curves on a sphere, self-intersecting or not. A metric space can be made out of S by defining a distance $d(p,q)$ between any two curves p, and q of S. Suppose an infinitesimal animal crawls along p carrying one end of a rope while another animal crawls along q carrying the other end of the rope. Suppose the two animals make the circuits p and q, respectively, just once. In this act a rope of a certain minimum length L will be required. The value of L will depend upon how p and q are traversed. The minimum value of L considering all the infinitely many ways of traversing p and q will be our definition of $d(p,q)$. It is not difficult to see that the triangle axiom (1.1) is satisfied. This kind of distance was first defined by the French mathematician Fréchet. Together with its obvious generalization as the distance between two surfaces, or two hypersurfaces, it has been immensely useful in mathematics. We shall refer to it again in connection with the existence of closed planetary orbits.

Another more algebraic kind of abstraction is the notion of a linear vector space B. The set of ordinary vectors in euclidean 3-space is an example. More generally the sum $x + y$ of any two elements in B shall be defined and satisfy the algebraic relations holding for ordinary vectors in 3-space. For example $x + y = y + x$, $x + (y + z) = (x + y) + z$, $a(x + y) = ax + ay$, etc., where a is any number. A vector space is termed *normed* if the distance from x to the null vector is defined, denoted by $||x||$, and if $||x + y|| \leqq ||x|| + ||y||$. One naturally supposes also that $||tx|| = |t| \cdot ||x||$ for any number t. The space B is converted into a metric space by taking the distance between x and y as $||x - y||$. As in the case of ordinary vectors one supposes that $||x|| = 0$ only if x is a null vector.

The set of real continuous functions f with values $f(s)$ defined on the interval $0 \leqq s \leqq 1$ affords an example of a normed vector space B. Functions f_1 and f_2 are to be added by adding their values for each s. One takes the norm of f as

$$||f|| = \max_{0 \leq s \leq 1} |f(s)|. \tag{1.2}$$

One of the theorems which underlies most of the linear aspects of modern mathematics is the theorem established by the Hungarian mathematician F. Riesz in 1909. Riesz states that an arbitrary continuous linear function F with values $F(f)$ defined for each f in B has the form

$$F(f) = \int_0^1 f(s)dg, \tag{1.3}$$

where g is a finite mass distribution defined over the interval $0 \leqq s \leqq 1$. Engineers or physicists will give the Stieltjes integral in (1.3) an appropriate interpretation as a moment, with $f(s)$ the length of a moment arm.

2. A CLASSICAL PROBLEM

Distinctive research strictly within the orbit of classical mathematics is the exception rather than the rule today. One such piece of research is due to Atle Selberg [1] (1) [2] in the analytical theory of numbers. For this Selberg was made the recipient of one of the two Field's medals and prizes recently awarded at the International Congress of Mathematicians held at Harvard University. I shall not write of Selberg's notable work on the Riemann zeta function, but rather on his singularly important discovery in 1948 of an elementary proof of the prime number theorem. This theorem was conjectured by Gauss as a young boy and characterized by Abel as perhaps the most remarkable theorem in all mathematics. The theorem states that the number $\pi(n)$ of primes smaller than n, has a ratio to $\dfrac{n}{\log n}$ which tends to 1 as $n \to \infty$. Proofs were first obtained by Hadamard and de la Vallée-Poussin. These proofs were of highly analytical character based on a sophisticated use of the Riemann zeta function. Hardy of Cambridge, England, stated in a lecture in Copenhagen in 1921, "No elementary proof of the prime number theorem is known and one may ask whether it is reasonable to expect one." The simplified proofs of Landau and Wiener could hardly be called elementary. It is one of the achievements of Selberg to have produced an elementary proof. Use is made of the properties of the logarithm in the form of a simple formula discovered by Selberg:

$$\sum_{p \leq n} \log^2 p + \sum_{p,q \leq n} \log p \cdot \log q = 2n \log n + O(n),$$

where p and q are primes and $O(n)$ is a remainder less in absolute value than a constant times n. Once the formula was discovered, a young mathematician Paul Erdös made an important contribution to the original proof. Selberg has recently generalized the prime number theorem, referring in his new work to arbitrary arithmetic progressions of primes.

3. DISTRIBUTIONS OF LAURENT SCHWARTZ (2)

The other recipient of a Field's prize and medal at the Congress of Mathematicians in Cambridge, Massachusetts, was a young mathematician, Laurent Schwartz, Professor of Mathematics at the University of Nancy. The theory of "distributions" of Schwartz is in part a synthesis and a simplification of results known previously, and in part an extension. It justifies processes of the operational calculus such as

[1] Born in Norway, now Permanent Member of the Institute for Advanced Study, Princeton, N. J.

[2] Boldface numbers in parentheses refer to references at the end of the paper.

those of the famous Heaviside, and properly interprets functionals such as the Dirac delta functional, all within the domain of well-defined mathematical entities. Schwartz distributions are linear functionals T similar to those considered by F. Riesz (see (1.3)). However, the values $T(\varphi)$ of T are here defined over a highly restricted space (D) of "testing functions" φ. We refer first to the 1-dimensional case in which φ together with its derivatives of all orders has complex values and is a continuous function of a point s on an s-axis and vanishes outside some finite interval for s.

With Schwartz we begin with the definition of a special distribution. Let f, with complex values $f(s)$ be defined for each real s, and be locally integrable (that is integrable over each finite interval of the s-axis). Then for fixed f and each φ in (D) the integral

$$\int_{-\infty}^{\infty} f(s)\varphi(s)ds = [f] \tag{3.1}$$

defines a linear functional over (D) denoted as in (3.1) by $[f]$.

If $\mu(s)$ is the integral of f from 0 to s, then the distribution $[f]$ defined in (3.1) has the form

$$[f] = \int_{-\infty}^{\infty} \varphi(s)d\mu(s). \tag{3.2}$$

One can regard μ as defining a mass distribution over each subinterval of the s-axis. More generally still, there are measures μ which cannot be given as integrals of a function f. But such a measure μ will still define a linear functional

$$\int_{-\infty}^{\infty} \varphi(s)d\mu = \{\mu\} \qquad [\varphi \text{ in } (D)]. \tag{3.3}$$

The functionals $\{\mu\}$ defined as in (3.3) by measures μ include the functionals $[f]$ defined by locally integrable functions $[f]$, but are still not the most general linear functionals T with values $T(\varphi)$ defined over (D).

It is these general linear functionals T which are the object of study of Schwartz. They are termed *distributions* and regard as generalizations of ordinary functions f. Schwartz imposes one additional condition on T, namely that T shall be *continuous* over D in the following sense. The complex numbers $T(\varphi_n)$, $n = 1, 2, \cdots$ evaluated for a sequence $\varphi_1, \varphi_2, \cdots$ of testing functions in (D) shall tend to zero in absolute value with $1/n$ provided each φ_n vanishes outside some finite interval independent of n and converges uniformly to zero while the m-th derivative, $\varphi_n^{(m)}$, similarly converges to zero for fixed m.

The historic Dirac delta function S represented by Dirac as a function, but more properly conceived as a measure defines a distribution

$$\{\delta\} = \int_{-\infty}^{\infty} \varphi(s)d\delta = \varphi(0). \tag{3.4}$$

The measure δ can be interpreted as a mass distribution with a null density at each point $s \neq 0$ and with a unit mass at $s = 0$.

One of the difficulties in classical analysis is that a continuous function f is not in general differentiable. However, if properly defined each distribution T has a derivative T'. Schwartz is motivated in defining T' by the fact that

$$[f'](\varphi) = -[f](\varphi'), \tag{3.5}$$

when f has a continuous derivative. Relation (3.5) follows from the definition (3.1) of $[f]$ and a suitable integration by parts. Following F. Riesz it is easy to see that $[f]$ uniquely determines f when f is continuous. Similarly a continuous f' is uniquely determined by $[f']$. In this case where f and f' are continuous it is accordingly natural to define the derivative of the distribution $[f]$ as $[f']$. The relation

$$T'(\varphi) = -T(\varphi') \tag{3.6}$$

is then a consequence of (3.5) setting $T = [f]$.

The relation (3.6) is now taken as the definition of the derivative T' when the distribution T is arbitrary.

Thus, contrary to the behavior of ordinary functions f, a distribution T generalizing a function f always has a derivative T'. There is a similar simplification when the derivative of a sequence $T_1, T_2, T_3, \cdots$ of distributions is sought. Schwartz says by way of definition that a sequence of distributions T_n, $n = 1, 2, \cdots$ *converges* to a distribution S if for every φ in (D), $T_n(\varphi)$ converges to $S(\varphi)$ as $1/n \to 0$. It follows from the definition of the derivative T_n' that $T_n'(\varphi) \to S'(\varphi)$. Thus a convergent sequence of distributions can be differentiated term by term without precaution in contrast to conditions which must be imposed when sequences of ordinary functions are to be differentiated.

We come to the problem of integration. Corresponding to a given distribution S it is easy to show that there always exists a distribution T such that $T' = S$. In particular if $T' \equiv 0$, then $T = [c]$, where c is a complex constant and $[c]$ is the distribution with values

$$[c](\varphi) = c \int_{-\infty}^{\infty} \varphi(s)ds.$$

Thus, both integration and differentiation are possible for all distributions.

We quote a theorem of Schwartz which shows the precise generality of his distributions T. If T is any distribution and Ω an open bounded set, then taking T over the set of all testing functions φ which vanish on the complement of Ω, T equals the derivative $[f]^{(p)}$ for a suitable choice of the integer p and locally integrable function f. Thus, the distributions introduced by Schwartz include the minimum number of new mathematical entities T such that the derivatives of distributions $[f]$ exist and are themselves distributions.

Following Schwartz we have sketched the 1-dimensional theory of distributions. The extension is readily made to the case in which f and φ are defined over an n-dimensional space. Partial derivatives and multiple integrals enter in an obvious extension of the preceding. Partial differential equations in distributions T as unknowns, convolutions, potentials, Fourier series and transforms, etc., can be effectively studied in terms of Schwartz' new medium. It is the contention of Schwartz that it is distributions and not ordinary functions which best represent the phenomena which engineers and physicists observe. This is a crucial point. It seems that the Schwartz theory is at the same time simpler and in many respects more complete than that mathematical world which it aims to replace. It is an excellent example of a natural growth from the body of classical mathematics.

4. VARIATIONAL THEORY

The calculus of variations has shown again in the last few years its vital central role. It has been used as an instrument by the Bôcher Prize winners, Schaeffer and Spenser in their work on "Coefficient regions for Schlicht functions." Radò and Cesari have clarified the nature of surface area and its representation. Morrey has given the first solution of the Problem of Plateau on a Riemannian manifold which cannot be covered with a single set of curvilinear coordinates. Bochner, Bergman, Schiffer, Ahlfors, Heins and others have used extremal methods in the study of analytic functions of one or more variables.

This generation has also seen the introduction of "Variational theory in the large" (3) as a new object of study intending to unify much of analysis. Another designation for this new theory which suggests its universal nature is "Equilibrium theory." Equilibrium configurations embrace the level points of surfaces, or hypersurfaces, extremals of all kinds, in particular the closed planetary orbits, the extremals of the Schröedinger integral in quantum theory, geodesics, minimal surfaces, and more generally, the solution of any boundary value problem that can be conceived as a stationary element of some integral or functional. Prior to 1925 minima have been the almost exclusive object of study in the calculus of variations. It is abundantly clear now, however, that stationary configurations in the free natural world practically never appear as minima of some functional. This is true, for example, of a free unit charge in the presence of other fixed electrostatic charges, or of a closed planetary orbit conceived as a stationary configuration of the Jacobi Action Integral.

The failure to study stationary configurations other than minima has been due to lack of methods. The most important impetus to this study was the discovery that every n-cycle (the generalization of a surface or 2-cycle) in the space of admissible configurations causes a stationary configuration if the n-cycle is "non-bounding."

For example, let us suppose a torus has an axis of revolution which is horizontal and that $z = f(x,y)$ represents the height of the point (x,y,z) on the torus above a point (x,y) in a horizontal reference plane. The circle g_1 generating the torus is a 1-cycle which is non-bounding on the torus. The circle g_1 determines a "homology class" defined as the class of all 1-cycles g such that g_1 and g taken together "bound" on the torus. One refers to $f(x,y)$ as the *height* or level of the point $(x,y, f(x,y))$ on the torus. The height of a 1-cycle g is the maximum of the height of the points. With these definitions it is clear that there is a 1-cycle g in the homology class of g_1, with g of least height in this class. Moreover, the point of maximum height on g is clearly a point P_1 on the torus with horizontal tangent plane. The point P_1 is a stationary point of $f(x,y)$ but not a point of minimum. It is rather a "saddle" point.

The inner vertical equator g_2 of the torus determines a second homology class and thereby "causes" a second level saddle point P_2 directly above P_1. The torus itself viewed as a 2-cycle determines a homology class on the torus every member of which completely covers the torus. A 2-cycle of least height in this class is afforded by the torus itself with a height equal to the maximum of $f(x,y)$ on the torus. We can accordingly say that the point of maximum $f(x,y)$ on the torus is a level point caused by the homology class of the torus. Finally, a point A on the torus is a 0-cycle and determines a homology class which includes each other point A' on the torus, since A and A' taken together bound an arc on the torus. The point of least height in this homology class is the point of minimum of f on the torus.

In resumé one sees that there are four independent homology classes on the torus; one of dimension 2, two of dimension 1, and one of dimension 0. Collectively they cause four level points of f on the torus, of which one only is a minimum. Under gravitational forces a point sliding on the torus would be in stable equilibrium only at the minimum point on the torus. The point of maximum on the torus is the most unstable. The saddle points obviously have aspects of stability and of instability. It is physically meaningful to say that a level point caused in the above way by an r-dimensional homology class has an *index* r of *instability*.

One of the major achievements of the variational theory in the large was to extend the theory of stationary points of functions to a theory of stationary curves, surfaces, or hypersurfaces regarded as elements on which an integral or even more general function is defined. For instance, consider a topological sphere S defined as a one-to-one continuous image of an ordinary sphere. One can take as a function the integral of length of a curve joining two fixed points P and Q on the sphere. The space of admissible elements is the Fréchet space of such curves metricized as in Section 1. The writer has shown that there is an essential homology class of each dimension n, $n = 0, 1, 2, \cdots$ and that each of

these homology classes causes a geodesic joining P to Q on S. There are thus geodesics of arbitrarily long length joining P to Q. Regarded as elastic cords lying in the surface of S the notion of stability is physically meaningful. The topological origin of these geodesics shows that there are elastic cords with every possible index of instability starting with the stable cord of minimum length.

These notions can be extended to the class of *closed* curves on S resulting in the theorem that there are (except for multiply covered closed geodesics which do not occur under general conditions) infinitely many closed geodesics on S. It is the generalization of these ideas to celestial mechanics and in particular to the problem of n-bodies which contains the most promising line of search for the existence of direct and closed planetary orbits. The topological indications are that there are infinitely many such orbits.

The extension of these ideas to functionals defined by multiple integrals was very difficult. It was finally accomplished in the typical case of minimal surfaces by Morse, Tompkins, and Shiffman, working with the abstract variational theory previously developed for this particular purpose by Morse. One of the most important consequences of the whole theory is the possibility of reversing the application of topology to analysis, applying the models discovered in the variational theory to solve fundamental problems in topology. Pitcher has recently shown the first possibility of the application of the topology developed by Morse in the solution of geodesic problems on the topological sphere, to the determination of certain homotopy classes of mappings of r-spheres on s-spheres.

The eminent Russian mathematicians Schnirelmann and Lusternik (4) early took an interest in this field obtaining important results concerning the minimum number of level points of a function on a manifold. Compared with the inherent possibilities of development the theory is in its infancy.

5. FUNCTIONS OF SEVERAL COMPLEX VARIABLES

One of the most difficult but most intriguing fields of research actively pursued today is that of analytic functions of several complex variables. The simplest definition of such a function is that it is analytic in a domain B if, in some complex neighborhood of any point $(a_1, \cdots a_n)$ of B the function can be represented as an absolutely convergent power series in the differences

$$z_1 - a_1, \cdots, z_n - a_n.$$

The theory of functions of a single complex variable as developed under the hands of the early masters is relatively complete. What makes the theory so difficult when $n > 1$ is that many of the methods and theorems valid when $n = 1$ fail when $n > 1$. This leads to the following general

approach. A theorem valid when $n = 1$ may admit a modified form of statement or proof which has an extension when $n > 1$. What are the modifications of this sort of real significance?

The fundamental theorem of Riemann that any simply connected region in the plane whose boundary consists of more than one point can be mapped conformally (that is with preservation of angles at a point) fails when $n > 1$. For $n > 1$ the notion of *pseudo-conformal mapping* is introduced. Such a mapping is required to be one-to-one and to be defined by an analytic transformation of the complex co-ordinates. In general two domains even with the same topological characteristics cannot be pseudo-conformally mapped onto each other as Poincaré made clear.

Another theorem in the case $n = 1$ for which the obvious generalization fails when $n > 1$ is the theorem of Picard that a function f of one complex variable, convergent everywhere but not a constant, cannot omit more than one value. In fact there exists a pair of entire functions

$$u = x + \text{(higher powers)},$$
$$v = y + \text{(higher powers)},$$

which represent a one-to-one continuous mapping of the space of complex variables (x,y) into a proper part of itself with the Jacobian of the transformation identically 1. See Bochner (5), page 45.

Another difference between the cases $n = 1$ and $n > 1$ is that when $n = 1$ the real part $u(x,y)$ of an analytic function f of a complex variable $z = x + iy$ is harmonic, that is satisfies Laplace's equation, and conversely any such single valued harmonic function is, locally at least, the real part of an analytic function f. When $n = 2$, for example, the real part $U(x_1,y_1,x_2,y_2)$ of an analytic function $f(z_1,z_2)$ of complex variables $z_1 = x_1 + iy_1$, $z_2 = x_2 + iy_2$, is doubly harmonic, that is harmonic in (x_1,y_1) and in (x_2,y_2), and hence satisfies Laplace's equation in the space (x_1,y_1,x_2,y_2). But not every such solution of Laplace's equations is doubly harmonic, and even if doubly harmonic is not in general the real part of an analytic function $f(z_1,z_2)$. Considering the tremendous role which harmonic functions have played in the case $n = 1$ it is natural therefore that functions U of some "extended class" should be used when $n > 1$ to play a role as similar as possible to the role of harmonic functions when $n = 1$. Such a class has been introduced by Bergman. He starts with functions U which are doubly harmonic when the domains of z_1 and z_2 are circular discs, and in the case of other domains, uses subclasses of functions V obtained from U by a pseudo-conformal transformation of the above domain of U.

In the case $n > 1$ it has been found useful to rely heavily on algebraic methods. The study of formal power series has been particularly effective in the hands of Bochner. Bochner, Martin, H. Cartan, Behnke, Thullen and Peschl have obtained elegant results in a domain of ideas

which we shall typify by a theorem of Carathéodory. Suppose S is a group of formal transformations of a space of n complex variables into a similar space. Suppose the coefficients of the formal series defining the transformation are bounded in absolute value for each given set of indices of a coefficient regardless of the element in S. Then as Carathéodory pointed out the elements of S are uniquely determined by their linear parts.

A study of functions f analytic on a domain B of n complex variables with f^2 integrable over B was made by Bochner and Bergman (6) around 1922. Closed systems of such functions $\varphi_1, \varphi_2, \cdots$ normalized and orthogonal certainly exist when B is bounded, and lead (taking the case $n = 2$) to a kernel

$$\sum_n \varphi_n(z_1,z_2)\overline{\varphi_n(t_1,t_2)} = K_B(z,t), \tag{5.1}$$

where $z = (z_1,z_2)$ and $t = (t_1,t_2)$ are points in B. Moreover, K_B is independent of the choice of the system $[\varphi_n]$. Of the many uses which Bergman makes of K_B one of the most interesting is his form of statement of the Schwartz-Pick Lemma. As formulated by Pick when $n = 1$ this lemma states that if a conformal transformation takes the unit circle into its interior then the hyperbolic length of a line segment in the unit circle is not thereby increased. With kernels K_B at his disposal when $n > 1$, Bergman is able to define metrics invariant under pseudo-conformal transformations and to generalize Pick's Lemma as follows. If a domain B is pseudo-conformally transformed into a subdomain G then a non-euclidean volume (or area) in the geometry of G is not increased when measured in the geometry of B.

Although it is only exceptionally that a domain B can be pseudo-conformally mapped into another when $n > 1$, nevertheless E. Cartan, Fuchs, Bergman, and others have produced results of great interest. In particular, Bergman has introduced a function J with real values $J(x_1,y_1,x_2,y_2)$ defined in terms of the kernel K_B and has indicated necessary and sufficient conditions for the pseudo-conformal equivalence of Reinhardt domains in terms of the topological properties of the level manifolds and critical points of J. In making this study Bergman refers to the theory of critical points of Morse as sketched in Section 4.

Finally, reference should be made to the novel work of Bochner on curvature and Betti numbers of compact complex Hermitian manifolds M_n connecting the p-th Betti number of M_n with the number of linearly independent pseudo-harmonic tensors of order p. Lichnerowicz has also made contributions to the same subject.

6. OTHER SIGNIFICANT CONTRIBUTIONS

The long-standing Hilbert space theory, under the influence of Weyl, von Neumann and Marshall Stone is being extensively perfected both

in its abstract form and in its applications to differential operators. In the theory of differential operators recent papers by Kodaira and Hamburger are significant. In applied functional analysis the work of Aronszajn, Friedrichs and Bers stands out. Dunford has produced significant papers in spectral and operator theory while Kakutani has written authoritatively on Ergodic theory and Hedlund on dynamics. With the variety of notions of integration which exist it is natural that abstract concepts of measure and integration should be advanced. Halmos and D. M. Stone have made contributions in this field. In the domain of topological algebra Gelfand, Kaplansky, Segal and Dieudonné have shown the way. These are fields rather more in algebra than in analysis.

In the important field of the Cauchy problem, and hyperbolic differential equations the classical work of Hadamard and Herglotz is bearing fruit. A most notable paper has been written by Petrowski. It is found somewhat difficult to read and Leray of Paris, France, has recently obtained similar results in a somewhat different manner. Bureau of Liège, Belgium, has made the work of Herglotz more explicit, while Gårding has written intensively on hyperbolic differential equations. The fixed point theory of Leray, stemming from ideas of Birkhoff and Kellogg and developed by Leray with Schauder before the death of Schauder at the hands of the Nazis is being extensively developed both in theory and applications.

Thus mathematics advances on many fronts with unparalleled vigor and imagination.

REFERENCES

(1) ATLE SELBERG, "An Elementary Proof of the Prime Number Theorem," *Annals of Mathematics* (2) 50, pp. 305–313 (1949).

(2) LAURENT SCHWARTZ, "Théorie des distributions. Actualités scientifiques et industrielles." Paris, France, Hermann, 1950.

(3) MARSTON MORSE, "The Calculus of Variations in the Large," Colloquium Lectures, American Mathematical Society. New York, 1934.

(4) L. LUSTERNIK AND L. SCHNIRELMANN, "Méthodes topologiques dans les problèmes variationnels." Paris, France, Hermann, 1934.

(5) S. BOCHNER AND W. T. MARTIN, "Several Complex Variables." Princeton, N. J., Princeton University Press, 1948.

(6) STEFAN BERGMAN, "Sur la fonction noyau d'un domaine et ses applications dans la théorie des transformations pseudo-conformes. Mémorial des sciences mathématiques." Paris, France, Gauthier-Villars, 1948.

TWENTIETH CENTURY PHYSICS

BY

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Prediction in physics requires some knowledge of initial conditions for the event which is to be predicted. In addition there is required an equation of motion or its equivalent. Another way is to look into past records for an analogous situation to the present. The future is predicted from this segment of history. Still another way is to extrapolate from the present and immediate past into the future.

The first method is no help in the prediction of the development of physics itself because we have no theory of the history of science. The second is inapplicable because the development of physical ideas is in essence a production of new concepts which have very little or no analogues in the past. There remains only the third. However, at the present time this procedure is of very doubtful value. The main problems of physics have been attacked by almost a whole generation of brilliant minds with very little success. It is therefore very likely that quite new ideas and points of view will be necessary for further progress in theoretical physics. It is very unlikely that they will be an extrapolation of current doctrine.

In experimental physics, the discoveries of the last generation have been so novel, so unlike the past, that it becomes clear that here again no extrapolation can be made with the slightest hope of success.

Nevertheless, there may be some rhythm in the development of physics which if understood would afford certain intimations of the future of this science. A brief review of the previous half century of physical thought and discovery may therefore be useful in this connection.

The problems of physics at the beginning of this century were numerous and profound. The outstanding questions were: the electrodynamics of moving media which concerned the Michelson-Morley experiment and related phenomena; the electrical constitution of matter and particularly the role of the newly discovered particle, the electron; the nature of X-rays; the explanation of the spectral distribution of temperature radiation; the anomalies in the specific heats of gases and solids at low temperatures and the theorem of equipartition in statistical mechanics; the significance of the peculiar properties of the photoelectric effect; the mystery of the origin of the line spectra and the extraordinary and puzzling regularities which were observed; the nature

of chemical binding and chemical valence; last but not least was the question of the structure of the electron, what holds it together and what is the nature of its mass.

In the next fifty years all these questions but one were definitely answered. The discovery of radioactivity and Rutherford's experiments settled the question of atomic structure. The atom will forever be a positively charged nucleus surrounded by a planetary system of electrons. The quantum theory of Planck solved the puzzle of temperature radiation and with Einstein's extensions of these ideas, the problems of the photoelectric effect and specific heats were well on their way to solution. Bohr's extension of Einstein's photoelectric relation led far to the solution of the details of atomic structure and the nature and origin of spectral lines. Spectral lines graduated from the stature of a puzzle to the most powerful tool for understanding atomic and molecular structure.

The step which is most characteristic for this century was the creation or discovery by Einstein of the theory of relativity, the special theory in 1905 and the general theory in 1916. The special theory gave a new insight into the nature of time and simultaneity, and quite incidentally settled the outstanding question of the electrodynamics of moving media. The general theory gave a natural explanation of universal gravitation. Even more than these specific contributions the theory of relativity removed almost all vestiges of anthropomorphic thinking from fundamental physics. Physical models after Einstein's work were no longer based on the properties of ponderable media, but rather became mathematical constructions guided by broad principles of conservation and invariance and other general ideas.

The Quantum Mechanics of Heisenberg, De Broglie, Schroedinger, Dirac, and Pauli marks the next great break with the past, and is another great step in the direction which Einstein initiated. All thought of a model is now gone and in a certain sense it is a break with the philosophical tradition of physics which always implicitly assumed the existence of an external reality. The Quantum Mechanics claims only to give relations between certain sets of observations. Only ghostly echoes of classical physics can be found in the quantum mechanical models of a physical system.

Up to the present writing, physical theory has hardly advanced beyond quantum mechanics. The tremendous experimental discoveries of the last twenty years of a host of new particles, neutrons, positrons, pi plus, pi minus, mu plus, mu minus and neutral mesons have not resulted in a definite breakdown of the quantum mechanics.

Of all the main problems which existed at the beginning of the century only the problem of the electron structure and mass remains, as intractable as ever. Even the discovery of the mutual annihilation of electron and positron to form two light quanta has not brought the

problem nearer to solution. The charge mass and statistics of the electron are empirical facts not brought into relation to anything else like Planck constant or the velocity of light. The same is true of meson theory.

Now at midcentury, physicists are confronted with a host of new problems: the nature of nuclear forces; the variety of seemingly fundamental particles; the quantization of charge and rest mass in particle physics; and the red shift of spectral lines in distant nebulae in the physics of the universe. However, it cannot be said at the present time that existing theory is really insufficient to deal with the problem. The mathematical difficulties which are involved in deriving detailed consequences of the theory are such that it cannot be said that they are wrong, although the numerical predictions are rarely verified by experiment in the field of meson physics.

The tremendous achievement of the last fifty years was not without a certain cost. Physics has moved far away from primitive intuitive experience. From this point of view the fundamental ideas of physics seem rather artificial. It is doubtful whether the great masters of the nineteenth century would be happy with relativity and quantum mechanics. Many of them would perhaps feel that our neat explanation of physical phenomena somehow missed the real point. The modern explanations rest on premises that are very far from nineteenth century thought.

It is similarly to be expected that physical theory of the next fifty years will cope with the present discoveries but again along lines which will be strange. The present difficulties with quantum electrodynamics and with meson theory have been intractable for almost two decades. It is hardly to be expected that the solution will be forthcoming in the near future. Very likely the most important experimental data are still to be discovered.

The future course of experimental physics is perhaps easier to chart. Extraordinary progress has been made in the postwar period. A number of synchrocyclotrons and synchrotrons are now in operation and the discoveries which have been made have been of the utmost interest. Still higher energy ranges, the billion electron volt region, will be available in a few years. These new instruments, coupled with the newer cosmic ray techniques such as photographic plates, give promise that in the next ten or twenty years elementary particle phenomena will be well understood from the experimental point of view.

In discussing the future of physics one cannot any longer separate oneself from the general social environment. Research in physics has become very expensive. Nuclear reactors, electronuclear machines, high altitude cosmic ray laboratories, balloon flights, airplane flights, and large groups of plate scanners are not cheap no matter from which pocket the money comes. Experimental physics cannot progress unless

there is generous public support. The public, therefore, has to be interested in research in physics for one reason or another. As a corollary, to elicit this public support, the physicist will have to learn how to create in the public an interest in and an understanding of his strivings in research.

Physicists will have to take a part in the teaching of science in the schools, colleges, adult education centers, the press, radio and television. This effort will create certain social values and attitudes which are greatly to be desired. Diffusion of the scientific tradition in the general public will make for a healthier national life and perhaps revive the optimistic spirit of progress which was such an attractive feature of the nineteenth century.

AERONAUTICS

BY

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Human flight occurred for the first time in the history of our race near the beginning of this century, December 17, 1903. The dream of flight is old. Men had long wondered at "the way of an eagle in the air." Leonardo sketched artificial wings. The Montgolfier brothers sailed with the wind in a balloon. Hardy adventurers leaped from high places with parachutes. Lilienthal slid from hill to valley in a glider two thousand times before his fatal crash. The simultaneous advent of benzine and the internal combustion engine, in the closing years of the 19th century, suggested to Langley and other pioneers the application of power to a glider to make a true flying machine. However, the principle of control in three-dimensional space was lacking. This lack was supplied in the Wright brothers' great invention.

Never has a new vehicle been born into a more favorable climate for its technical development. Applied science and the industrial revolution of the 19th century had piled invention upon invention: machine tools, railways, steamships, the electric telegraph, photography, the typewriter and typesetter, and finally the motor vehicle. It seemed, at the dawn of our century, that man needed only to accomplish the conquest of the air to dominate his planet. In our own time man has achieved this conquest to an extent unforeseen by the most optimistic.

The Wright airplane disclosed a sustaining wing structure, engine-driven propeller, and means for controlling attitude in pitch, roll and yaw. This basic type has continued to the present day. Its performance was rapidly improved by application of the advancing technology of the new century. Research and development were stimulated by generous national subventions, and two wars poured billions into the production of bigger and better flying machines.

In his 1950 Wilbur Wright Memorial Lecture,[1] Sir Richard Fairey traced fifty years of expenditure on aeronautics, world-wide, making intricate allowances for the shrinking values of money and varying exchange rates. The curves of Fig. 1 show that expenditures of America and Britain were relatively modest during the period between wars, but that the world total rose abruptly between 1934 and 1939 into the billions (Germany, Japan, Italy, Russia). Sir Richard stops his analysis with 1948, by which time the total expenditure by all nations in peace

[1] *Jour. R. Ae. Soc.*, Vol. 54, pp. 405–432, London, 1950.

and war adds up to 256 billion U. S. dollars since the Wright brothers made their contribution to the technology of transportation. Orville Wright was not unaware of the military value of the airplane, since the first sale was to the U. S. War Department. However, he always contended that he and his brother Wilbur thought of their airplane as a contribution to international communications, trade and good will. Perhaps the next fifty years will prove him to have been right in the long run.

Designers were at first the inventors, then engineers and scientists. The demands of the airplane led to the creation of strong light alloys, high octane gasoline, high output engines, and special operating equipment using radio, radar and auto pilots. A new science of aerodynamics

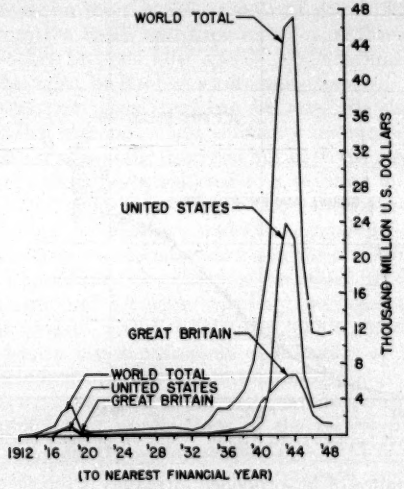

FIG. 1. World expenditure on aviation.

was evolved to serve designers. New impulses were given to the classical but somewhat sterile theories of hydrodynamics, elasticity, radiation, gyroscopics, and navigation. Old ideas for a gas turbine were resurrected and applied with spectacular success.

Taking speed records of propeller-driven airplanes as a measure of progress, the increase in 47 years has been from about 40 to nearly 500 miles per hour, or at a rate of some 10 miles per year of effort. Simply projecting this trend suggests that the next 50 years should bring the airplane's speed record to 1000 miles per hour. A fallacy must be present here, because the newspapers inform us that jet-propelled

research airplanes have repeatedly flown at supersonic speeds. This sounds like 1000 miles per hour already.

Closer examination of the position shows that the jet-propelled airplane is not the airplane of the Wright brothers; something new and revolutionary has been added. A radically lighter and more powerful means of propulsion eliminating the propeller is a mutation that upsets statistics of past growth. The engine and propeller-driven airplane has indeed made a normal growth curve, topping off between 1940 and 1950, with a maximum sea level speed of the order of 450 miles per hour.

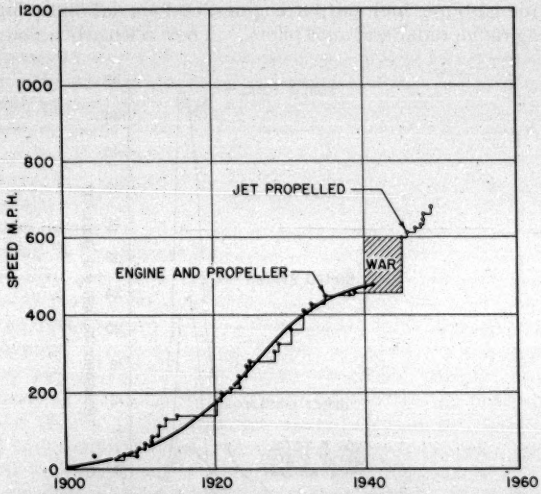

FIG. 2. Sea level, airplane speed records. (After H. Luskin, Douglas Aircraft Co.)

The performance of jet-propelled airplanes is too recent to establish a trend from which to venture a forecast. All we know is that we shall have to do with a new kind of airplane to which vastly increased thrust can be applied. How fast will it go? The answer seems to be as fast as required.

The limits on useful speed will be imposed by practical considerations of range, load, control, and safety. Extreme speed can only be attained with an outrageous rate of fuel consumption even when advantage is taken of the diminished resistance of the air at high altitudes. Higher speed means shorter range or the sacrifice of pay load. Furthermore, wings may be clipped to a degree that makes control for take-off and landing impractical. Pushing possibilities to the limit, one can replace the pilot by automatic or robot controls, launch by catapult or

from another airplane, and expend at the end of flight. Such an ephemeral insect-like thing is the guided missile, featured by the popular press but otherwise clothed in security wrappings. Rocket-propelled for less than a minute, 12-ton German missiles landed in London from a launching point in France with a ton of explosive. The velocity exceeded 3000 miles per hour over part of the trajectory.

Exploitation of the rocket art for military purposes will no doubt continue, with substantial improvements in frightfulness over the German models. Engineers who should know better have aroused public anxiety by predicting intercontinental push-button warfare, satellite vehicles circling the earth like moons, and space ships for interplanetary excursions!

The possibility of such space ships is usually based on Dr. R. H. Goddard's concept of a multi-stage rocket. A giant rocket as big as a cruiser starts from the earth and then ejects a smaller one and so on until the last rocket escapes into space. Calculations can be made to show that this might be done at enormous expense.

Another speculative calculation can be made to show that a few pounds of fissionable material might suffice for an escape rocket. This idea shifts the problem from the source of power to the means to apply it. The atomic energy must be transferred to a working fluid, such as hydrogen, to be ejected at high velocity. The material to withstand the temperature involved is unknown, and the engineering data necessary for the development of an atomic rocket are not available for scrutiny.

We already use rockets for exploring the upper air, for accelerated take-off of airplanes and for other auxiliary purposes and, no doubt, further uses will appear. Since rockets and, to a somewhat less degree, ram-jet power plants, are so extremely extravagant of fuel, they seem likely to find their best applications to weapons.

I would hesitate to say now what might not be possible in 1999, but it is safe to predict that applications of the rocket principle for air warfare will be the subject of intense effort.

I leave out of this discussion design trends in military airplanes. The design of military airplanes, like that of warships, is governed very largely by the foreign policy and military plans of the nation, checked by intelligence of actual or potential foreign equipment, and controlled by the general state of technology at a given time.

The international situation for the next 50 years is unpredictable. There is now an evident trend toward preparation for war. Under this trend, aeronautical development is now directed toward the needs of national security but technical advances in military aeronautics are ultimately applicable to civil uses. We have twice observed the stimulating effect of war on postwar air transportation.

In a period of peace, research results, as they disclose new knowledge, suggest to designers in a competitive industry new solutions. From

their experiments come practical improvements, usually minor, but over the years their effect is cumulative.

The trends of immediate improvement are usually evident from a comparison of current designs with research data not yet applied. There is always a time lag before research findings come into general use, but such trends justify only short-range predictions, perhaps over a ten-year rather than a fifty-year period.

For example, it is evident that the gas turbine is revolutionary in its effect of affording more power and hence higher speed to modern airplanes. The reciprocating engine is mature and efforts to improve it have reached a stage of diminishing returns. The turbine is simpler, lighter and more compact. Its big disadvantage is its youth, and consequent occasional unreliability and a tendency to extravagance. Youth will be outgrown and hence one may safely predict reliability to be promptly established. The fuel economy is now relatively poor, but three ways to improve it are known.

First, and most readily, fuel economy can come from higher compression of the combustion air. A current compression ratio of 4 to 1 can be raised to 8 or even 12 to 1 by using more powerful compressors. The design principles for such compressors are now established. Early application should bring fuel economy at high cruising speeds down to equal that of the ordinary engine.

Second, raising the temperature of the products of combustion before entrance to the turbine will both improve fuel economy and increase power output. The current limit on allowable temperature is due to the metals available. Research indicates the possibility of better heat-resisting metals, ceramics and their combination ceramels. Furthermore, experimental schemes for turbine blade cooling indicate interesting possibilities for raising gas temperatures with present blade materials. Eventual success with higher temperature should bring fuel economy down to that of the best engines.

Third, it is known that a substantial gain in economy can be had by the use of heat exchanger surfaces to transfer some waste heat from the exhaust to the compressed air for combustion. Taken with the other two improvements, it should be possible to attain a fuel economy superior to that of any previously known aircraft power plant. However, heat exchangers will not be adopted quickly. They involve increased weight and space, and a complication that threatens reliability and ease of maintenance. Perhaps, marine and stationary gas turbines will pioneer this avenue.

I believe that the propeller is the simplest and most efficient machine for converting torque to thrust. It is man's invention. It is not found in nature. If the gas turbine is such a superior power plant, it is a natural idea to gear it to a propeller to make it more effective than when its exhaust jet alone is used to give thrust.

The jet is certainly simple. It weighs nothing but is somewhat wasteful, especially at low airplane speeds. The kinetic energy of the small diameter high-velocity jet is all lost. Only its momentum gives thrust. The propeller also creates a jet in its "slip stream" but this is a large low-velocity jet in which the ratio of momentum (thrust) to kinetic energy is high. Good propellers have an efficiency of as much as 88 per cent.

Over the years the speed of commercial air transports has lagged the airplane speed records by 15 or 20 years. When the speed record was 400 miles per hour, air transports cruised at 200. Now the new transports can cruise at better than 300 miles per hour. As military experience with high-speed flight accumulates, we may expect the speed of air transports to follow with a conservative lag but probably not so great as in the past.

It had long been considered that propellers become inefficient at an airplane speed of much over 400 miles per hour. Then the tip speed of the propeller blades became excessive. However, recent research suggests a change in propeller design which should render propellers effective beyond 500 miles per hour, and perhaps to 600. There are practical difficulties to be overcome, but discounting them, it appears that the gas turbine driving a propeller promises the more powerful drive needed to get higher transport speed, while retaining the high efficiency of the propeller. The prediction of the early appearance of faster air transports with geared gas turbine-propeller drive is easy.

Whether, in a more distant future, there will be reason to fly passengers at supersonic speeds is perhaps doubtful. There certainly will be good reason for bombers to fly at the maximum speed the art permits. When they do, propellers can not be used and jets will take over. When air transport wishes to emulate the speed of bombers, they also will have to use jet propulsion.

In the present state of knowledge, considerations of economy favor the propeller-gas turbine power plant. For routes with stops at 1000 mile intervals, the advantages of speed may be controlling, and jet propulsion gas turbines used. For feeder line local service, for freight and general utility work, for private (not common carrier) airplanes the propeller and engine seem best.

Any engineer will agree, I think, that the different means of propulsion will be used in future where there is a real advantage. Research and development may change relative merits from time to time, and unpredictable inventions may occur. Just now, it appears that the gas turbine has good possibilities for substantial improvement, whether used for jet propulsion or to drive a propeller.

Air transportation is already big business. In 1949, more than 16,000,000 passengers were carried by U. S. air lines, with only one fatality per 100,000,000 passenger miles. Statistically, the safety

record looks good. The risk is certainly insurable, but this does not comfort the individual passenger when he reads of a spectacular crash in his newspaper. Nor is the passenger comforted when his flight is cancelled by reason of bad weather. The cancellation is in the interest of his safety, but he thinks first of his missed appointment and general inconvenience.

Figure 3 shows the continuous rise in air transport speeds for the last 25 years, but the mean line always lies well below the record speeds of Fig. 2. The new British jet-propelled transports, COMET and

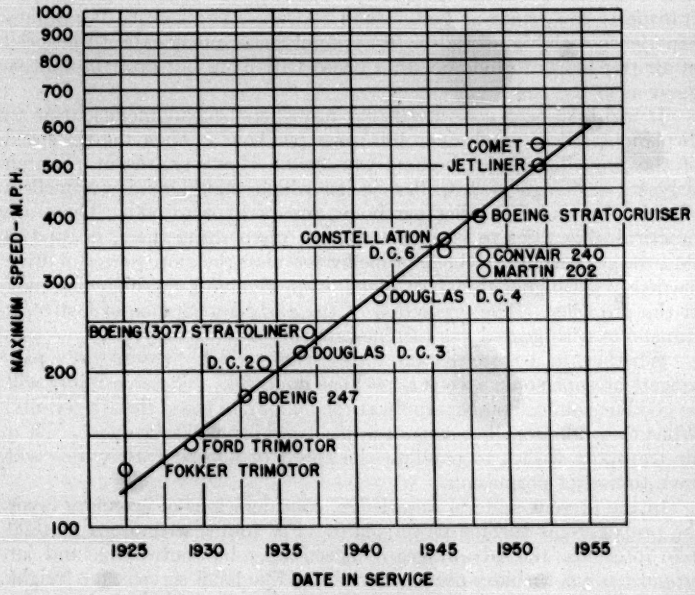

FIG. 3. Speed of transports. (From *Aviation Week*, May 22, 1950.)

JETLINER, promise the continuation of the secular speed increase we have been accustomed to. I have no reason to project the straight line to intersect 1000 miles per hour at 1970. This would be outside the chart, and over into the region of transonic speed where critical aerodynamic trouble can be predicted.

Too rapid adoption of possible design improvements in air transport and unusual efforts to maintain schedules in bad weather work against safety. Air transport cannot proceed at once to exploit many possibilities of the art suggested by current research. A number of difficult

problems must first find practical solutions. No doubt solutions will be found, but the timing is uncertain. The next fifty years should bring solutions to the following difficulties that now appear formidable.

1. *Fatigue*

As airplanes fly faster, the wings must be thinner and of sharper profile. Such wings are flexible. They bend and twist in gusty air and under the shock of landing. The effect of rough air is magnified by higher speed. The structure of the wings is strained repeatedly and may gradually lose strength by fatigue. Research has accumulated data as to the repetitions of strain per 1000 hours of flight on various transcontinental and transocean routes, but is as yet unable to predict the safe life of the airplane.

2. *New Materials*

The fatigue problem is allied to the problem of new materials and methods of construction to make stiffer wings. For example, there are possibilities in the use of adhesives instead of rivets, sandwich construction of metal and plastic, new alloys and, finally, the recent availability of titanium.

3. *Stability and Control*

To fly faster requires new configurations to avoid the aerodynamic disturbances that appear at critical speed near the speed of sound. Swept-back wings have been found valuable at high speeds but unfortunately introduce trouble with control when approaching a landing. Also some high-speed airplanes exhibit stability vagaries which seem too quick for a human pilot to cope with. This suggests more dependence on automatic controls and servo mechanisms.

4. *Physiology*

Airplane design must always consider the limitations of human physiology. The paragraph above refers to the pilot's reaction time. The human air-breathing animal requires definite rations of oxygen, carbon dioxide and water vapor, in a strictly limited range of temperature and pressure. If he be housed in an air-conditioned cabin with a pressure corresponding to an altitude of some 8000 ft., he is quite comfortable. However, in order to attain high speed, air transports of the future might fly at 40,000 ft. or higher. Mechanical failure to maintain cabin pressure could result in fatal decompression. Air transport operators presumably will require assurance that the chance of failure of cabin pressure will be as remote as structural collapse of a wing.

5. *Air Navigation*

The limitations of the present airway navigation and traffic control systems prevent the expeditious and safe handling of the current traffic

load. Elements of a comprehensive system of radar range, surveillance and precision-approach ground equipment are already being installed at some airports and military flying fields. A complete system covering the North American continent could be followed by its world-wide extension during the next 50 years, if the international climate is favorable to free communications and traffic. The full development of all-weather flying depends on this.

6. *Airports*

The great potential growth of air commerce depends not only on air navigation facilities but also on the availability of suitable airports. The higher cruising speeds now anticipated require, for economical operation, higher wing loading. Take-off and landing characteristics limit such fast air transports to the largest airports. The newer airliners are probably at the limit for safe operation from the majority of large airports. It is probable that runway lengths will be increased at some of the great international airports but the larger number of municipal airports cannot expand. This will bring about a distinction between high-performance air transports for long distance routes, and air transports of more modest performance, making frequent short flights between airports located near every considerable center of population, and feeding in to the large transcontinental and international airports.

7. *Helicopters*

Air transport between airports cannot reach full commercial stature unless improved means are developed to get the passengers, mail and freight to their ultimate destination. Motor vehicles are the present means, but are costly and slow. For short flights, time in the air may be exceeded by the time required for ground transport. The helicopter appears to have the characteristics required to solve this problem but at present is complicated, costly and relatively inefficient as a load carrier. It has proved of value for special services where the airplane is hopeless, such as for rescue operations, some kinds of crop dusting and, in general, for regions with no roads or landing fields. It has not yet been able to compete with motor transport.

The present handicaps of the helicopter are not fundamental, and future designs may be simplified by eliminating the articulated rotor with its unfavorable vibration characteristics and limitation on forward speed from blade stalling.

It will not require inventive genius to work out the application of an autopilot to correct difficult handling characteristics which now effectively prevent blind flying in slow-speed approach conditions. The future high-speed helicopter should have a payload equivalent to an airplane designed for the same speed and still retain the ability to hover.

Some mention should be made of so-called convertible aircraft, intended to operate as a helicopter at take-off and landing and to convert itself mechanically into an airplane during flight. Many schemes to accomplish this have been proposed, all involving great complication and risk, and violating most of the principles of good functional design. However, I can only echo the general of the last war, who said, when shown plans for an unusually ingenious but tricky new weapon: "Even if it works, I don't want it!" The prospect for the development of fast efficient helicopters should make such a combination vehicle unnecessary.

The evidence from current trends in research suggests that the helicopter may ultimately replace the airplane for short feeder-line flights, that turbo-propeller airplanes will serve normal intercity traffic and that transcontinental and transoceanic flights will be in very high altitude turbojet airplanes of very high speed. Six hundred miles per hour cruising speed is not unreasonable.[2]

Airplane designers might profitably use the time needed by their power plant colleagues to bring the turbojet economy and reliability to a commercially attractive standard by improving the safety and livability of airplane passenger compartments, and by solving the very critical problem of the fatigue life of the airplane's fundamental structure.

In the meantime, commercial air transport may stagnate at about the present level, due to congestion at airports attempting to handle both local and long distance flights with inadequate equipment. An international system of air navigation and traffic control is essential to the full utilization for a peaceful world of the "conquest of the air" which our generation so proudly claims.

Competition, both military and commercial, forces increased airplane performance. Improved performance has come in the past from more efficient aerodynamic forms, combined with more powerful and efficient propulsion systems and fuels. It appears from current research that aerodynamic progress in the transonic and supersonic speed regions is paralleling the rate of progress formerly achieved in the lower region. One can only conclude that the manifold advantages of exploiting the conquest of the air will ensure that the necessary effort will be made over the coming half century.

[2] Prediction of J. J. O'Connell, Jr., Chairman of Civil Aeronautics Board, United Nations broadcast, April 22, 1950.

POSSIBLE AND PROBABLE FUTURE DEVELOPMENTS IN COMMUNICATION

BY

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Communication in its broadest sense means transfer of information, whether instantaneously as in conversation or delayed as in books or phonograph records, whether over short distances or to remote locations, whether in the form of words or in the subtle expression of a countenance, whether between men or machines. For the purpose of this paper I propose to limit myself to instantaneous communication by electrical means, not because it may be expected that advance is to come only in that limited sphere but because developments in electrical communication have already had so profound an effect on human affairs and because the promise of further revolutionary advances is so definite and its implications so far-reaching.

Even thus restricted, the task of predicting the future might perhaps better be assigned to a psychologist or other kind of "social scientist" than to a physicist or an engineer, for so limitless are the possibilities of developments in electrical communication already close at hand that the probabilities as to the range and extent of their application depend upon the demand that may arise more than on new instrumentalities which may be devised to meet that demand. However, a good starting point is to assess the physical means already available or nearly within our grasp. That I can do with some assurance that I am dealing with matters of fact, or at least realizable fact, and not mere fancy. If I have the temerity to venture further, it is only because extrapolation is so well justified by the course of past events.

Only a little more than a hundred years ago telegraphy was born. About a quarter of a century later it had spanned the ocean and it was not long thereafter until a network of wires was spun around the earth to give substantially instantaneous world-wide communication by written words. Today not only words but information in any graphic form can be dispatched between any points where men may be—on land or sea or in the air.

Seventy-five years ago the telephone was born. Forty years later it spanned the continent, and very soon thereafter the oceans. Now there is no place where the telephone may not reach and with it the sense of personality and feeling that only speech with its nuances can convey and that means so much more than mere words can say.

Less than twenty-five years ago the sight of distant objects was first transmitted to remote points by wire and by radio. The day is almost on us when one may see across the continent and when all over our broad land the sound and sight of a single event at any place can be experienced by anyone who chooses to take the trouble of turning the knob of his television set.

All means of electrical communication involve sending electric waves over wires or through the air, and a principal factor in the advance of communication during the past century has been the extension in the range of frequencies employed. It is in the form and frequency of the waves that information resides. As it has become possible to utilize more and more rapid vibrations in the physical instrumentalities used in electrical communication, and as it has thus become possible to communicate with waves of higher and higher frequency, so it has become possible to transmit correspondingly more and more information.

Bell's invention of the telephone grew out of his endeavor to utilize higher frequencies for telegraphy so that he might send more messages over a telegraph wire. Later, radio telegraphy and after that radio telephony grew out of the use of frequencies so high that energy could be radiated efficiently into space. The use of these high frequencies on wires and coaxial cables has made possible the simultaneous transmission over them of hundreds of telephone conversations. The development of television required the use of extremely high frequency systems. In contrast to telephony which utilizes a frequency band of thousands of cycles per second, television requires millions of cycles. With frequencies of billions of cycles per second, radio waves can be concentrated in beams by means of lenses or reflectors of moderate size and thus can be relayed from station to station across the country to carry television programs and telephone conversations in great number.

From the point of view of extension of the frequency range, this first century of electrical communication breaks into two epochs. During the first 60 years there was a relatively slow extension of the frequency capabilities of electromechanical structures on the one hand and electric circuits and transmission lines on the other. It was during this period that our understanding of high-frequency alternating current phenomena was developed and that many of the inventions that were keys to the achievements of the later epoch were made.

With the invention by Lee de Forest of the amplifying thermionic vacuum tube 44 years ago, a new epoch began. This device provided a valve or gate for electric currents that could be opened or closed by degrees and as rapidly as millions of times per second. It thus opened the way for a tremendous expansion of the frequency range available for electrical communication. This was the beginning of the era of electronics with its revolutionary consequences. Perhaps no single event in modern technological history has been more significant.

As the capabilities of electron tubes have been improved the frequency range employed in communication has continued to expand. We have now reached the point where waves of 6 billion or more cycles are used in commercial installations. We have built a tube in the laboratory that amplifies waves of 50 billion cycles and there is no reason to think that this is the limit.

As we go to these new realms of frequency we tend to revert from free waves in space to waves carried by conducting structures. Waves of such extreme frequency are limited as to their usefulness for broadcasting or radio relay systems because they are absorbed by fog and rain. However, they are capable of being sent through hollow metal pipes of moderate size and the amount of information they can carry will be tremendous when means are developed to make effective use of them.

Important as it is to electrical communication, frequency band width is not the sole factor that limits the amount of information that may be carried by a wire line or a radio beam. The noise that is present to interfere with transmission is also a factor. We have only to think of conversing in a noisy room or a subway to realize that the presence of disturbances places limitations on our ability to pass information, though the limitations due to noise are of a different sort from those determined by band width. In electrical circuits we always have both of these factors, the noise factor being an aggregate of effects extending down even to the random motion of electrons in matter itself. Yet it is only in the last few years, through a penetrating mathematical analysis known as "information theory," that the exact relations have been brought out and clarified whereby noise and frequency band width together determine the information-carrying capacity of a transmission channel. The conclusions are of such great interest and importance to communication that I could not let them pass without mention. They range from the proposition, on the one extreme, that with the ideal and practically unrealizable condition of no noise present it would be possible to reduce without limit the band width required in a circuit, to the very practical and already demonstrated fact that with moderate increase in frequency band width the interfering effects of noise can be eliminated to any desired degree. Knowing these relations in quantitative terms, we now have a way of attacking the problems of communication on a more fundamental basis. This will lead not only to better understanding but to better utilization of the tools we have and it will point the way to designing better ones.

In communications research, we are continuously seeking new ways to extend communication and to reduce its cost, and also to develop new purposes it can serve for human convenience. The extent to which new systems are applied and improvements in existing systems are made, comes down to a matter of cost measured against value.

Thus in assessing the probabilities of future developments in communication, we have not only to take into account physical possibilities but we have also to make some judgment as to values and costs, being ever mindful that costs that now appear prohibitive may some day become trifling in consequence of research and invention yet to be done and also of the effect on cost of large quantity production.

Today we find ourselves in the midst of a television boom. After being "just around the corner" for a large part of the thirty years since it was born, television is suddenly upon us and presenting problems in its social and political implications that far outweigh matters of costs of sets or quality of reproduction of visual images. This new art is obviously in its infancy; we can confidently expect better quality of picture, more refined and reliable apparatus, and in every way more in a technical sense for our money, including of course television in color. Immature as television still is in a technical sense, the art of using it effectively for entertainment and education is still less mature. In its development the scientist and engineer have offered a challenge to society, the outcome of which we can hope will be for the good of all.

It would be a bold prediction indeed that would set limits that the art of television would not surpass and I shall not attempt to do so. I should like, however, to mention some of the uses it may be put to outside of the broadcast field. Some are fairly obvious, such as the observation of industrial processes at a distance, display of goods to customers at remote locations, face-to-face conferences of dispersed individuals or groups. One of the most puzzling questions regarding television is the extent to which it may some day come to be an adjunct to ordinary person-to-person telephony. Present costs and frequency band width requirements seem to rule it out altogether from incorporation in telephone systems of today. Another deterrent to this use of television is that modern telephony gives us so nearly all that we now desire in conversation between individuals far removed from each other that it seems doubtful that many would be willing to pay for the addition of vision, even at the lowest cost one can imagine being achieved. Nevertheless, the experiences of motion pictures with sound, and of television broadcasting, give proof of a demand for joining sight with sound that will surely lead to some use of person-to-person television combined with telephony. The extent of such use must remain for the future to unveil; I would not even venture to prophesy.

Great as are the possibilities opened up by the development of television, it should not be assumed that they will obscure developments in other aspects of electrical communication. For instance, telephony seems a well-stabilized art but actually it has never become static and is ever the subject of gradual change as science uncovers new means for its improvement.

While we can reach almost any point on earth where we might wish

to talk to another person, there are still places we cannot reach quickly enough, and to which we cannot talk well enough. In particular, talking across the ocean is, on occasions, not so good as talking across the continent, because of interference caused by sunspots and atmospheric conditions in certain seasons and years. If transoceanic telephony could be made as good and as cheap as we should like, there would be demand for hundreds of circuits where we now have tens, just as the demand for transcontinental circuits now runs to many hundreds.

To telephone across the ocean, we are still dependent on radio waves rather than on wires. The cables that carry telegraph messages are not capable of carrying telephony over great distances. Telephone cables capable of spanning the ocean and even of carrying many conversations simultaneously have been devised, but the cost of such cables is still too high to justify their installation. One may, however, well risk the prophecy that within the foreseeable future, some economical means will be found for increasing by many-fold the provisions for transoceanic telephony and for developing it to a degree comparable with present transcontinental telephone service. The means which will eventually be employed cannot be clearly envisioned now. The solution might prove to be an even more radical advance in submarine cables, or it might be some adaptation of microwave radio systems such for instance as airborne radio relays, or it may be some means we have not yet even thought of.

Important as is the overseas use of radio telephony, the actual extent of application of radio telephony over land is far greater. Radio must of necessity be our sole dependence for communication with automobiles and airplanes. The rapid growth of this type of telephone service in the postwar period gives ample demonstration that mobile telephony is still in its infancy. Not every automobile traveler needs a telephone in his car, but there are many who do, and more who have yet to discover its value. Radio telephony is also used extensively and in increasing amount for point-to-point communication. Most notable is its use in microwave radio relay systems that serve as alternatives to coaxial cable for transmitting large groups of telephone conversations and television programs.

Even with all the progress that radio has made and has in prospect, there seems to be no chance that it will replace wires or other types of conducting structures for most of our electrical communication. Indeed the indications are quite in the other direction. As the total amount of communication increases, the radio spectrum will become more crowded and its use will tend to be restricted to those purposes for which it has unique advantages over wire. The same considerations point to the development of more efficient use of wire or other structures such as coaxial cables and wave guides. As the load for them increases, their use for wholesale transmission becomes more economical. One can

already foresee, with the development of tiny and powerful amplifying elements, the possibility of applying even to the short local circuits of urban telephony some of the techniques that have multiplied the usefulness of long distance wires. Particularly promising in this connection is the newly invented "transistor" that utilizes the peculiar electrical qualities of semi-conducting crystals. It amplifies as does the vacuum tube, but unlike the vacuum tube requires no vacuum and no current to heat a filament.

Communication to be effective and useful, however, involves more than carrying messages, speech or vision from one person or place to another. It requires quick and reliable establishment of connections. The machinery to make these connections is the unseen part of the modern telephone system. This, too, is an ever-changing aspect of telephony, where the trend, as in so many other things, is to do more by machine and less by hand. Now there are being applied to long distance circuits methods that will eventually make it possible for subscribers to dial remote points as they now dial points close at hand. Records of such calls will be made automatically and it is only a short step from this to the automatic preparation of the subscriber's monthly bill.

The machines for establishing and recording connections perform functions that suggest almost human, or superhuman, abilities. They receive a number from the subscriber and remember it; they transform it from the decimal system of numbers into a number system better suited for the machine to use. If the switching mechanism should fail, they detect and record the cause of failure and make a second attempt to establish the connection. In the new long distance systems they can search alternative routes to remote destinations to provide against overloading or interruption of circuits.

These complicated machines used in telephone switching are closely akin to the electrical computing machines about which one hears much these days. The use of electrical devices for computing is certainly still in its infancy and great things can be expected from it. Computing machines and machines of many other kinds can be tied together on a nation-wide basis. An example is the teletypesetter which makes it possible to produce simultaneously the same newspaper or magazine in different parts of the country. Another promising field for electronic communication is in the control of airplanes which perhaps some day will be guided throughout their course by automatic means to insure against collision and the blinding effects of fog. Indeed, communication between machines over long distances is an art as yet very little developed that holds great promise for the future.

The network of wires and radio beams that spans the nation and ties together individuals and communities has frequently been likened to the nervous system. In the development of remote control of

machines, we see the beginning of a motor nervous system. The auditory nerves of the telephone system are already well developed and are still growing. The visual nervous system is as yet in an early state of evolution. Other uses of this nervous system that we cannot now imagine are certain to evolve, for there is much about communication that we still do not understand.

There is no reason to believe that the capacity of human brain power for uncovering new knowledge and applying it to useful ends is approaching a limit, even in such a well developed field as electrical communication. It might even be that the solving of such a baffling problem as how birds chart their course in their annual migration would uncover a new lead in communication research. The nervous systems of animals and of man in particular are in themselves electrical communication systems of which we know little. The brain waves of the electroencephalograph of the clinician are but a crude clue to electrical action within and outside of the brain.

Truly, for those whose labors are directed towards improving communications, there are still new worlds to conquer. Where we shall be led by the developments that will come from research, is an interesting matter for speculation, but of one thing we may be sure: the benefits to society will depend far more on the capabilities of human kind in general for making use of what is made available than on the capabilities of scientists and engineers for making new devices.

HOMEOSTASIS IN THE INDIVIDUAL AND SOCIETY

BY

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One of the great ideas introduced into medicine by Claude Bernet is that of homeostasis—that is of a mechanism in the living organism which maintains the internal environment at a level at which healthy life is possible. Our blood pressure, the rate of our pulse, the rate of our breathing, the action of our kidneys, are all determined by homeostatic mechanisms which generally function so well that we do not notice them and, when they fail to function, bring on acute disorders such as fever, dyspnoea, tachycardia, uraemia, and the like.

A generation ago, it would have been difficult to find outside of the human body adequate analogues of these homeostatic mechanisms. One indeed was well-known, that of the governor in the steam-engine, and this special mechanism has been the theme of a classical paper by Clarke Maxwell in the 1860's. But the fact that the steam-engine governor was but one of a multitude of mechanisms, which we now class as the feedback type, regulating not only the speed, but the position, or the temperature, or some other property of physical systems, had not come to general consciousness. In these feedback systems an error of performance is returned to the system as a partial basis of its future performance, and in this way swings up and swings down are corrected when they are begun, without waiting for them to take on large proportions. At present, one of the cheaper means for introducing such a correction and for performing the combinations which make it possible, is the use of the vacuum tube.

Feedback mechanisms in general increase the uniformity of performance of a system whatever the load may be. Strictly speaking, this needs a severe qualification. If the load should be excessive and the amount of feedback demanded by the load also excessive, the feedback mechanism will unstabilize performance rather than stabilize it. Such a system will embark on an ever wilder series of oscillations until it breaks down, or at any rate the fundamental laws of the performance change.

In my book *Cybernetics* (John Wiley & Sons, The Technology Press, Hermann et Cie., 1948) I have given a parallel discussion of living and mechanical feedback mechanisms. I wish to call to the attention of the reader the existence of feedback mechanisms which contain both a living and mechanical part. There has been a recent invention[1] at the

[1] R. Bickford, *EEG Journal*, May, 1950.

Mayo Clinic of a mechanical anaesthetist, which regulates the depth of anaesthesia of an animal or a human by an injection device which injects barbiturates into the veins, or ether into the breathing mask, and the injection is measured in accordance with the depth of anaesthesia of the animal as made manifest through its electroencephalogram, which is directly interpreted into a mechanical basis for the injection. This principle is in the long run manifestly the right way to regulate anaesthesia, and it amounts to an artificial chain of homeostasis combining elements in the body and elements outside. If the validity of this method of homeostasis be granted in the one case of anaesthesia, we may scarcely expect anaesthesia to be the sum total of its usefulness. There are many conditions of great peril which are the result of a breakdown of homeostasis.

A very simple one, and also a very unusual one is that of curare poisoning. If there were a way for the degree of paralysis of the muscular endplate to be scanned for muscular performance, it would be an ideal thing to treat curare poisoning by a respirator whose intensity of action was regulated correctly by observing the paralysis of these endplates; or perhaps a better method would be to use an apparatus reading continuously the CO_2 concentration in the blood. Again, the medication of the heart is notably difficult, and requires great skill and judgment. It may well be in the future that when the signs of an incipient coronary catastrophe are present, we may learn of some drug whose dosage may be determined by a properly designed mechanical reading of the electrocardiogram.

Frankly, without stepping beyond the limitations of the layman in judging in what cases such a treatment is possible and in what cases it is not, I am very sanguine about the future possibilities of feedback-regulated therapy.

Besides these vital phenomena of homeostasis, there are a considerable number which belong to posture, and to the living phenomena of voluntary performance rather than to the maintenance of a livable internal environment. Your one-legged man finds that his artificial leg gives him less information concerning the state of his joints than he really needs to walk with the greatest freedom. I am not the only person who has suggested to various Government agencies that it is highly desirable to treat the problem of artificial limbs as essentially a problem of feedback, by attaching to the joints strain gauges, recording by vibrators on the normal skin of the amputee. But like my other colleagues who have maintained these ideas, I have not found my voice echoed in official quarters. I may be permitted to suspect that the misfortunes of the maimed constitute a sort of vested interest.

Besides the importance of the feedback in motor deficiencies, sensory deficiencies also have an important feedback element. It is foolish to separate deafness as inability to hear, from dumbness as inability to

speak. Either or both constitute an inability to use sound waves as an effective two-sided tool of conversation. The deaf patient has no adequate way of monitoring his own voice, so that it shall accord with the standards of hearing people. If then he is given an adequate way of turning sound waves into sensory experience, this monitoring and the feedback it gives rise to will enable him to use his own voice so that it conforms to the canons of an adequate conversational tool. This has been our object in a series of experiments at MIT, in which we have tried to secure a tactile reception of sound waves adequate for the understanding of speech.

The blind man's cane is a feedback. It enables him to create disturbances by which he can scan the world around him. The design of better pieces of apparatus of this sort promises to mitigate greatly the lot of the blind, even as a similar ability almost assures us of the possibility to mitigate the lot of the deaf.

There are, however, regions and important regions in which we are all deaf and blind. The horror of walking through an atom-bombed city is that one may kill oneself without hurting oneself. The Geiger counter is a great tool to prevent this, if we have the presence of mind to look at it, but a Geiger counter alone will never have the compelling force of the searing pain of ordinary low-temperature fire. Any adequate Geiger counter to be carried by those whose occupation may at any time expose them to the peril of nuclear radiation, should not merely follow the radiation in a visible scale or by audible clicks. When the radioactive level goes beyond a certain point, it should hurt the person carrying it definitively and sharply. Similarly, if we could only make the incipient stages of cancer or of heart disease desperately painful, we should go far to eliminate them from the list of killers. They are painful enough indeed when they are thoroughly established, but this is generally not until the cancer has metastasized into large regions of vital tissue, or until the life of the coronary patient hangs on, on one or two patent arteries. Thus with all the power that we now possess, the body corporeal does not possess an adequate homeostasis for all its needs. Even less does the body politic.

The body politic is not without homeostasis, or at least the intention of having homeostasis. This is what we mean, for example, by calling the Constitution of the United States "a Constitution of checks and balances." It is our intention that the administration serve as a protection against any inordinate assumption of power on the part of the Legislature, and that the Legislature watch jealously over any incursions of the Executive into its own particular realm, while the Judiciary should observe the action of both and see that they conform to national traditions. I have said, "national traditions." There is the rub. On the one hand, we do not wish to be bound forever to decisions made in the past, under what were perhaps irrelevant circumstances.

On the other hand, national traditions will not function without a certain minimum of historical consciousness and sagacity on the part of the population at large. We are very sensitive about a policy which will lead to great unemployment or to great poverty, provided we may expect this policy to come to ripeness within our own time. On the other hand, as the history of the slogan, "Peace in our time," has shown, we are not very sensitive to a future catastrophe, however certain we are that it will arise to plague our children when we are laid in our graves. The future is terribly unreal to the majority of us. And how shall it not be, when the past is equally unreal to us?

The continuity with the past which belongs to the older settled regions of Europe and to a lesser but a very real extent to the older settled regions of the United States, is dependent not only on an acquaintance with written history, but with the continual presence of the houses, the roads, the farms and the cities established by past generations, and with a familiarity with the mode of life which developed them. When a Yankee basketmaker will show you in his shed the tools which his great grandfather forged from bog iron and which he learned to use after the custom of the Indian to split the annual rings of the red ash and make his splints, he will do so with a guileless sense of the contemporaneity of the past, which is very far removed from the pride of the New England aristocrat in his genealogy. His past lies in his barn with its bins, its tools and its baskets; and if his thoughts carry him back to a time when the roads were just emerging out of the Indian trails, and the mode of life of the white man was subject to continual borrowing from that of the red man, his thoughts will also carry him forward to at least some crude consideration of the time when his children's children will plow his land and make his baskets. To such a man, the possibility of a stabilizing mechanism is present, and he will have a real reaction to it, for otherwise his house will become an empty cellar-hole, and his land the possession of a stranger. This is for him a death beyond death, in a very real and present sense.

However, in the great cities, or in the esoteric hot house civilization of Southern California, where a man's parents lie in the soil of Iowa or Nebraska, and a man's neighbors are pursuing their purposes in life without any reference to his own, it is useless to ask that he should regard his own grandchildren as anything but slightly modified sorts of strangers. The span of social memory which is needed for the homeostatic action of an historical sense is too great for transients and squatters. Yet without this span, the regions which have been built out of the desert and the burnt hillsides in a magnificient defiance of nature, represent far too much of a defiance of nature to possess the elements necessary for their continued existence. To respect the future, we must be aware of the past; and if the regions where that awareness of the past is real have shrunken down to a pin point on our vast map, then so much the worse for us and our children, and our children's children.

SOME PROSPECTS IN THE FIELD OF ELECTRONICS

BY

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The boundaries of the field of electronics, like those of almost any branch of technology, are vague. Enclosing within them everything in which the electron plays a vital function would certainly take in too much territory, yet, restricting the domain of electronics to devices involving the employment of free electrons only would leave out such items as crystal triodes and diodes which, by reason of their function, have been quite generally claimed by workers in electronics.

It must be recognized, however, that until recently the free electron has been responsible for the role which electronics has come to play in the modern world. Its extraordinarily large specific charge makes it possible to impart to it high velocities with the aid of moderate electric fields and to deflect its path with ease by either electric or magnetic forces. This is the reason for its effective use for the amplification of rapidly varying currents or voltages and the generation of high-frequency oscillations in the vacuum tube, for the indication of voltage and current variations in the oscillograph, and for the generation of picture signals in the television camera and the reconstruction of the televised scene in the viewing tube. The same property proves valuable in the detection and measurement of light by phototubes and in the generation of X-rays in X-ray tubes. Finally, in the electron microscope the scattering properties of matter for fast electrons, the nature of their interaction with magnetic and electric fields, and their wave characteristics combine to permit the use of free electrons to extend the recognition of microscopic detail by two orders of magnitude.

The history of electronics can conveniently be divided into four overlapping periods. In the first, ushered in by DeForest's invention of the audion and terminated, approximately, by the First World War, electron currents were controlled in vacuum tubes in much the same manner as a steam valve controls the flow of steam in a pipe. No more attention was paid to the behavior of the individual electrons in the tube than is customarily expended on the motion of the individual steam molecules in the valve. The English designation "electron valve" is singularly fitting for this period.

In the succeeding period, taking up much of the 'twenties and 'thirties, the directed, rather than random, character of electron motion in vacuum was applied in the cathode ray tube and for improving the efficiency of amplifier and oscillator tubes by proper shaping and aligning

of electrodes. The electrostatic secondary-emission multiplier phototube, in which secondary electrons are guided from one electrode to the next by a careful adjustment of electrode shapes, is a typical product of this epoch.

The third period, beginning some time before the Second World War, further subdivided the beams of electrons into groups and dealt primarily with the latter. This subdivision was either on the basis of time, the electrons being bunched at certain phases of an applied high-frequency field as in the klystron or magnetron, or of space, as in image-forming devices; the electron microscope and the image tube are typical representatives of this group. A somewhat different form of group selection, on the basis of time and place of injection, occurs in the betatron.

The fourth period in the development of electronics, in which we find ourselves at present, is concerned with the control of electrons within solids. Here, with crystal diodes, transistors, photoconductive pickup tubes, etc., we have barely made a beginning. However, in large part with the aid of the typical products of the preceding periods, which are at the same time undergoing continuous further development, this period should prove at least as productive as any of the earlier ones.

Let us visualize some of the trends in the evolution of the electronic art in the near future. We may distinguish here between the development of new devices and the extension of their practical application. In the field of amplifying tubes and oscillators we can safely predict that the stress will continue to be placed more and more on types suitable for the very-short-wave-length region of the radio spectrum, where the time of travel of the electrons can no longer be neglected in comparison with a period of oscillation. In oscillators and narrow-band amplifiers the tube geometry will, as now, for example, in magnetrons and klystrons, be determined in large part by the frequency of the oscillation generated or amplified. At the same time, wide-band amplifying tubes will increasingly be provided by devices in which energy is exchanged between electron streams and traveling wave fields, as in the traveling-wave tube, the double-stream tube, and others. Similar techniques of energy interchange, in reverse direction, serve to provide high-energy electron beams in linear accelerators.

Concurrently, there will unquestionably be a continued great increase in the application of electronic components in all departments of life. In heavy industry case-hardening and annealing of metal parts by radio-frequency currents already plays a large role. Glueing of plywood, heat-detonation of explosive rivets, sealing of metal tubes, welding of plastic sheet, and dehydration of antibiotics are other effective uses of radio-frequency heating. In the food industry the same technique may be employed for the sterilization of packaged foods and liquids, the blanching of vegetables, and specialized cooking opera-

tions. Food sterilization by bombardment with electrons in the million-electron-volt range also appears to be a promising field. In medicine radio-frequency fields may not only be employed for certain types of therapy, but, in addition, the "radio knife" which seals the capillaries severed in an incision, is a valuable aid in surgery.

Up to this point we have considered the power output of electronic devices; of quite as great importance is their employment for analytical

FIG. 1. A modern desk-type electron microscope.

and diagnostic purposes. The use of very-high-energy X-rays for the detection of flaws in machine parts, facilitated by electron image amplifiers, will become increasingly standard practice. Similarly, spectroanalysis of the alloys used for machines and manufactured products with the aid of automatic recording equipment employing mult plier phototubes will be much more general than it is at present. Isotope tracer methods in chemical and metallurgical studies will call for scintillation counters and other electronic equipment in increasing numbers.

The same devices will find extended use for diagnosis, therapy, and research in medicine and biology. Many time-consuming routine operations, such as the making of blood counts, can certainly be carried out more speedily and accurately by electronic methods. Television techniques applied to the study of the variation in skin potential distribution already hold much promise for the rapid diagnosis of brain tumors and heart conditions, yielding information in much more readily interpreted form than that supplied by the conventional electroencephalograph and electrocardiograph. There can be little question that the measurement

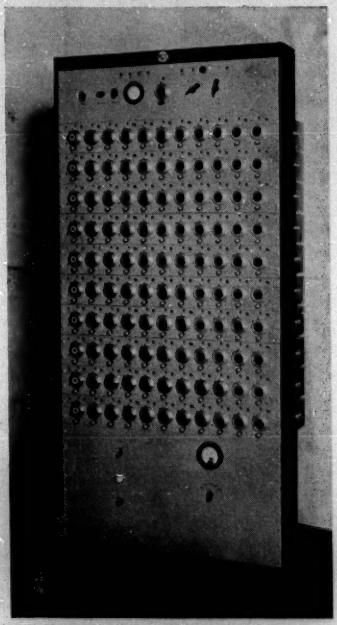

FIG. 2. An electronic analogue computer: the simultaneous equation solver.

of body potentials and their variation, made possible by amplifying equipment of high sensitivity, will prove of increasing value in many other areas of medical diagnosis and biological research.

The electron microscope, also, is likely to find not only increasing use as a research tool in biology, chemistry, and metallurgy, but, on the basis of research findings, as a diagnostic aid as well. The introduction of smaller, more compact, models of the electron microscope, supplementing the larger research instrument, should prove particularly valuable here, just as in routine chemical tests. At the same time,

fundamental research probing into basic life processes, the growth mechanism of crystals, and innumerable other frontier regions of knowledge will find the electron microscope indispensable.

Even broader in its applications than the electron microscope is the electronic computing machine. It not only supplies quantitative answers to problems in fields governed by known laws, however involved their application may be; it also greatly accelerates the discovery of laws governing physical phenomena through the rapid comparison of the predictions of an hypothesis with actual measurements.

There are two types of electronic computing machines: the analogue computer and the digital computing machine. In the former the variables in the equation to be solved are represented by electrical quantities, such as current or voltage, and the operations occurring in it, by the characteristics of the circuit and tube elements making up the computer. Both in principle and in function, the electronic analogue computer is closely related to the mechanical analogue calculating device, which, in the form of Bush's differential analyzer, ushered in the era of large-scale computing machines.

Examples of electronic analogue computers are McNee's differential analyzer for the solution of ordinary differential equations (1);[1] Goldberg and Brown's simultaneous equation solver (2); and the numerous auxiliary circuits employed, in radar technique and elsewhere, to simplify the presentation of data. By its very nature the application of the analogue computer tends to be specialized, its accuracy limited.[2] Even so, it has proved its usefulness in countless ways, in a saving of time and effort and the elimination of human error.

By contrast, the digital computing machines are quite universal in their application and their accuracy is only limited by the number of significant figures which can be entered on them. As the name implies, the digital computer deals with numbers represented by a sequence of digits. The primary difference between the electronic digital computer and the familiar mechanical computing machine is a difference in the speed with which the electronic machine can perform the elementary arithmetical operations. This quantitative difference, however, leads to important qualitative differences: If the time in which the elementary arithmetical operations are performed is measured in microseconds, the basic advantage of the high speed of the machine is lost unless the time of transfer from one operation to the next, also, is measured in microseconds. This necessarily eliminates the role of a human operator from all intermediate operations and even prohibits the employment of mechanical devices in the major portion of the computation process. The human operator only enters in the setting up of the machine for a given calculation and the reading of the final results.

[1] Boldface numbers in parentheses refer to references at the end of the paper.

[2] Eventually, as in the simultaneous equation solver, a rapidly converging process of iteration may be employed to achieve results of arbitrary accuracy.

To perform its function effectively the electronic digital computer hence requires, in addition to a group of electronic computing units, a set of "fast," electronic, memories, in which an intermediate result can be stored until needed for a later operation, as well as a command system on which the complete sequence of operations to be performed by the machine may be recorded. Additional, "slow," memories, in the form of magnetic or punched tape, can be employed, furthermore, for the storage of large quantities of information, such as tables of functions, which may be fed into the fast electronic memories on order.

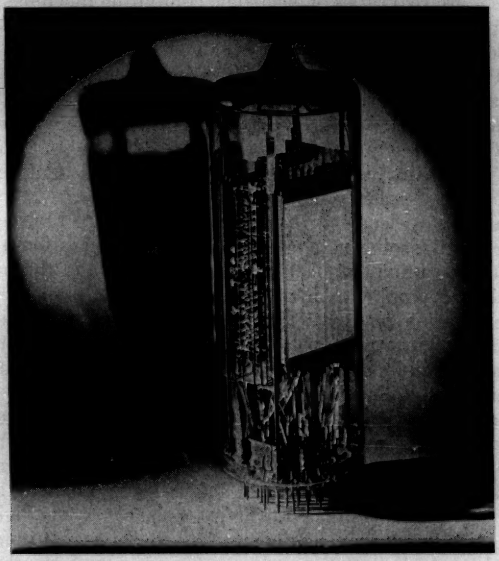

FIG. 3. The SB-256 tube, an efficient electronic memory.

Much ingenuity has been expended in devising satisfactory electronic memories. The essential feature of all electronic memory devices is the presence of elements with two alternative stable states which are maintained indefinitely unless subjected to new electrical "writing" impulses. The Eccles-Jordan trigger circuit, containing two vacuum tubes so connected that, in equilibrium, one tube conducts while the other is cut off, constitutes such a single element of memory. More recent devices, such as the cathode-ray tube memory of F. C. Williams (3) and the SB-256 tube of Rajchman (4), by comparison, utilize the properties of the secondary emission of insulators to provide several hundred such elements (corresponding to the storage of an equal number of binary digits) in a single envelope.

The last few years have seen great advances in the magnitude, scope, and organization of digital computing machines. These will unquestionably continue and further expand the role of electronic methods in science and in our economic organization. It may well be, however, that electronic computation will achieve its greatest triumphs through the integration of analogue computing devices, with their ability to short-circuit extensive numerical calculations in specific applications, in digital computing systems. In fact, it seems scarcely thinkable that effective headway can be made with extremely complex problems such as are encountered in weather prediction unless all available techniques are combined to best advantage.

Possibly the most striking demonstration of the power of electronics to the average man has occurred in the field of television. The development of this new industry has far outstripped the predictions of the most

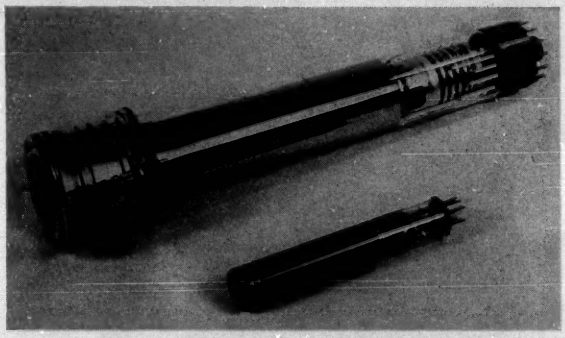

FIG. 4. Size reduction and simplification in television pickup tubes: the image orthicon and the vidicon.

extravagant prophets of a few years ago. It requires little imagination today to foresee for the television set a universality comparable to that of the kitchen range or the refrigerator. Numerous articles have dealt with the probable effect of this new factor on education, social patterns, and the economy, and I shall make no attempt to add anything to their conclusions. Technically, also, the pattern for the future has in large part been established for broadcast television, with the creation of a sound basis for the smooth change-over or side-by-side existence of color and black-and-white television (5). Nevertheless, a host of interesting engineering problems whose solution will lead to the simplification and improvement of different phases of television equipment and television service remain to be solved and, to judge by the recent past, will be solved in original fashion.

There is another aspect of television development which has not received, and probably will not receive, nearly as much attention as

broadcast television and which may yet, eventually, turn out to be of even greater significance. This is industrial television—the utilization of television techniques in industry, research, education, commerce—in short, in all fields apart from broadcasting. The basic industrial television system, in the form of a self-contained, cable-connected link incorporating a television camera and a combined viewing and control unit, enables the observer to transfer his vantage point to dangerous and inaccessible locations; to view simultaneously several, spatially widely separated scenes; or to share an intimate view with a large number of other observers without mutual interference. The first condition is realized, for example, in the watching of carefully shielded

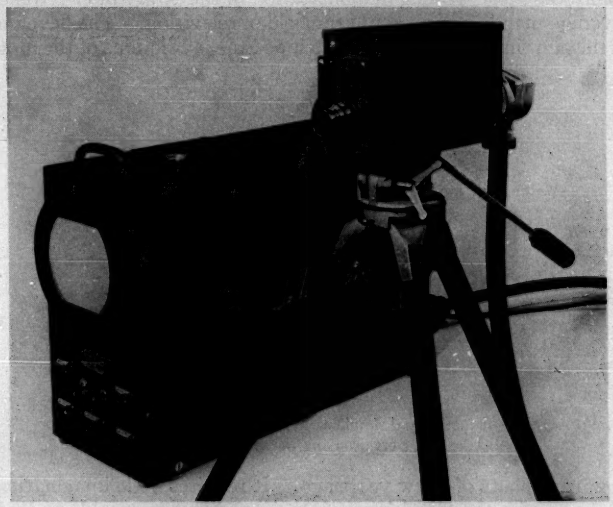

FIG. 5. An industrial television system: camera and control unit.

radioactive reactions from a protected point, the checking of engine performance by a camera mounted on the underside of an automobile chassis, or the observation of the proper filling of the scoops in strip mining by a camera placed directly above the scoop; the second, by the simultaneous observation of indicating instruments at a number of substations from a central station; and the third, in the watching of surgical operations on television receivers linked to a camera mounted above the operating table or the presentation of microslides at high magnification to groups of students; in the last instance the microscope image is projected directly on the target of the pickup tube in the television camera and the enlarged image is either viewed directly on a home receiver or projected on a screen by a theatre projector.

In all these instances compactness and simplicity of the television camera is an essential requirement. A great step forward in this direction has been the recent development of the vidicon (6), a highly sensitive television pickup tube with a photoconductive target. This tube, though only 1 in. in diameter, is capable of transmitting high-quality television images at moderate light levels. Furthermore, the extraordinary simplicity of the vidicon simplifies control of the camera from a distance: In a typical example of present industrial television equipment (7), the control unit incorporating a monitoring kinescope is con-

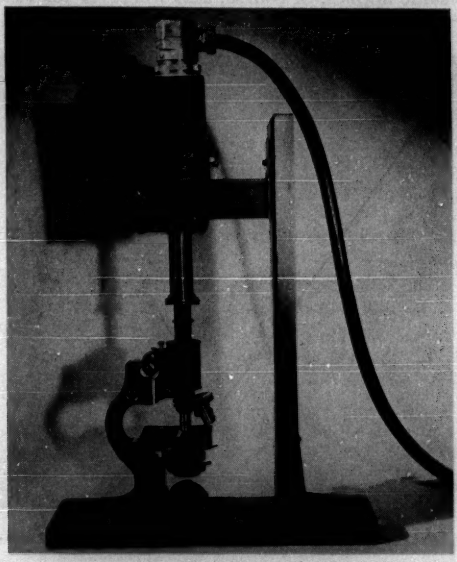

FIG. 6. Television for the class room: industrial television camera mounted on a microscope.

nected by a 500-ft. cable to the camera. This cable not only transmits the video signals from the camera to the kinescope, but, in the opposite direction, transmits electric power and centering, focusing, and deflection signals from the control unit to the camera.

The small dimensions of the new camera tubes also lend themselves well to their employment in color television cameras transmitting simultaneously picture signals for the three primary-color components of the picture. Perhaps of even greater value in many practical applications is the observation of objects in three dimensions, made possible by the employment of a stereo television camera. Here two vidicon tubes, with a pair of objectives controlled by a single focusing move-

ment, are mounted side by side. In viewing the stereo receiver linked to the camera, the eyes of the observer are in effect translated to the position of the two stereo camera objectives—and, at the same time, endowed with the greatly increased focusing range or "accommodation" of the latter.

An example where such three-dimensional observation is particularly valuable is the presentation of surgical operations to medical students. Here the relative spatial position of the surgeon's tools, the incision, and the organs on which the operation is performed is of primary importance. The same applies, of course, also wherever television is employed for instruction in mechanical operations. The immediacy and

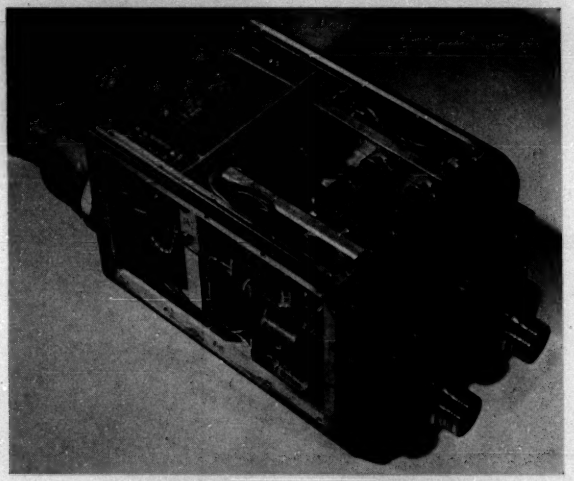

FIG. 7. Stereo television camera for conveying three-dimensional images.

flexibility of television demonstrations as compared, for example, with demonstrations by means of motion picture film should render them an exceedingly effective aid in the process of education.

In the development of networks of television broadcasting stations we have witnessed the use of micro-wave links paralleling that of coaxial cables. In industrial television, too, situations arise which can only be met by the use of such links, even though this materially complicates control problems. Examples are the transfer of visual information from the ground to aircraft and *vice versa*, for example, as an aid to navigation, the transmission of scientific data from rockets, and the sending of astronomical information from balloon-mounted telescopes at a sufficiently high altitude to escape major atmospheric disturbances.

The extraordinary range of applications of television is best realized when it is recognized that television does for the sense of sight what radio and the telephone have done for the sense of hearing. Insofar as the amount of intelligence acquired by the average person through vision is incomparably greater than that acquired through hearing, we can safely predict that the revolution wrought in our lives by television in its various forms may materially exceed that brought about by the development of means for auditory communication.

As I have already mentioned, the most recently developed television pickup tube, the vidicon, employs a target consisting of a photoconductive material, that is, a material which conducts electric current under the influence of light. Employed in a simple photosensitive cell, such a material does not emit free electrons into space and hence does not fit into the realm of "electronics" in the narrower sense. Yet, materials from the larger family of the semiconductors, to which it belongs, are playing an increasing role in electronic apparatus—not only as components of tubes utilizing electron beams, such as the vidicon, but also quite apart from vacuum devices: in the form of the crystal rectifier and the transistor they fulfill certain requirements previously met only by vacuum tubes.

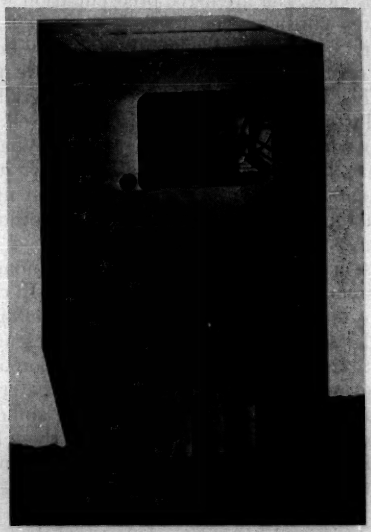

FIG. 8. Stereo television receiver: polaroid screens in front of the two viewing tubes and in front of the eyes of the observer make one image visible to each eye.

Whereas, at present, there is little reason for expecting wholesale replacement of vacuum tubes by their semiconductor equivalents—certain basic shortcomings of the latter militate against this eventuality—the crystal elements will not only find increasing use in specialized apparatus where compactness is of primary importance but also be incorporated more and more into the design of more conventional electronic equipment. Here also the trend is toward compactness, as exemplified by the increasing use of printed circuits. In this connection the crystal diodes and triodes represent but one phase of a constant search for improved components for electronic apparatus. From another point of view, the intensive preoccupation with the properties of the solid state, which has led to their discovery and development, is creating a fund of knowledge which has already borne rich fruit in the development of efficient phosphors, ferromagnetic materials, and crystal counters. This is bound to contribute materially not only to the electronic industry, but all other industries as well, and to supply effective new tools for scientific investigation. Whatever the future of electronics may be in the ensuing half century, it is certain to profit from fundamental research as it has in the past and to repay its debt generously in the form of instruments and methods to carry out the tasks of research.

In the past half century electronics has demonstrated its ability to annihilate distance for both sound and sight. In countless ways it has aided human safety and relieved man of routine efforts. To the scientist it has proved itself an indispensable aid in research. No prophet is needed to state that, in the future, the application of electronics in these fields will be even wider, its usefulness even greater; more than that, as the past amply shows, no prophet can have sufficient imagination to predict, at the present time, just what forms these further applications, this increased usefulness may take. Yet one thing is certain: In the future as in the recent past electronics will cooperate with the other branches of science and technology to achieve the satisfaction of physical needs, the extension of human knowledge, and the freeing of man's spirit for creative effort.

REFERENCES

(1) A. B. MACNEE, "An Electronic Differential Analyzer," MIT Research Lab. of Electronics, Tech. Rep. No. 90, Cambridge, 1948.

(2) E. A. GOLDBERG AND G. W. BROWN, "An Electronic Simultaneous Equation Solver," *J. Applied Phys.*, Vol. 19, pp. 339–345 (1948).

(3) F. C. WILLIAMS, "A Storage System for Use with Binary-Digital Computing Machines," *J. Inst. El. Eng.*, Vol. 96³, pp. 81–100 (1949).

(4) J. A. RAJCHMAN, "The SB-256 Memory Tube," to be published in *RCA Review*.

(5) RCA Laboratories Division, "A Six-Megacycle Compatible High-Definition Color Television System," *RCA Review*, Vol. 10, pp. 504–524 (1949).

(6) P. K. WEIMER, S. V. FORGUE AND R. R. GOODRICH, "Vidicon—Photoconductive Camera Tube," *Electronics*, Vol. 23, pp. 70–73, May, 1950.

(7) R. C. WEBB AND J. M. MORGAN, "Simplified Television for Industry," *Electronics*, Vol. 23, pp. 70–73, June, 1950.

MATERIALS

BY

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INTRODUCTION

In his presidential address before the American Chemical Society meeting, September 9, 1950, Dr. Ernest H. Volwiler discussed the difficulties involved in making predictions of the future in science.

Dr. Volwiler said, "Of prophecy I shall be most cautious, for the affairs of man lack the rigid controls which one can apply to a scientific experiment in the realm of inanimate chemical or physical reactions. Where the research scientist himself becomes a part of the experiment he is seeking to perform, we know all too well the great variation and the unpredictability of the results. So it is with the world where all living men are part of the gigantic, ever-changing experiment we call civilization."

He also quoted from the American Chemical Society presidential address of Dr. Harvey W. Wiley some fifty years previous, in 1901, in which Dr. Wiley, in his address on the "Dignity of Chemistry" undertook to predict the state of the science in chemistry in 1976 (which year would mark the centennial celebration of the American Chemical Society).

Dr. Wiley considered in his prophecies the material and population situation and changes expected in the following 75 years. To the extent that a mathematical calculation of reasonable certainty could be made, it is obvious that some of his predictions are reasonably accurate, but where the mind of man could influence the normal course he was often wrong, sometimes to the extent of over optimism and some times he under guessed to the extent that what he predicted for 1976 took place in 1926 and now we are many times beyond the original estimate.

Dr. Volwiler has pointed out that there are often extensive errors of markedly over and under-estimating in scientific forecasts, "for where basic fundamental knowledge is at hand the application of that knowledge has the tendency to come faster than one may anticipate. Where the basic facts of a given field are not at hand, however, forecasts frequently become fantasy and often take far longer than one might predict."

Among the predictions of Dr. Wiley was that this country should have a population of 225 million, which will probably be reasonably

near correct considering the increase in the past 50 years. This, however, was something that could be extrapolated from known previous data with only little chance of an appreciable error. Dr. Wiley felt that by 1976 this country would have an annual governmental budget of $4,000,000,000—which he greatly underestimated—and that there would be at least 10,000 members in the American Chemical Society. Actually there are now, after 50 of the 75 years have elapsed, over 60,000 members. This enormous growth of science beyond the predicted or expected growth is the cause of our concern about exhaustion of available material and the anticipation with which we now look for new and almost undreamed-of materials.

It would appear from experience with earlier prognostication that there are three types of predictions: (*a*) those which are reasonably obtained by extrapolation from data in the past and present; (*b*) those which are normally of type (*a*) but are disturbed or distorted by the unpredictable factors of the future; and (*c*) those which are essentially the results of unpredictable factors and bear little or no relation with existing procedures or knowledge.

Population changes are obviously an example of the first (*a*) predictable changes. Numbers of scientists working in a given field are examples of the second (*b*) type where there is a known expectation coupled with expected expansions or contraction due to the unpredictable demands. Such developments as atomic energy, television, jet planes, and metallic aluminum are examples of the third type (*c*) where sufficient data were not available at the time of prediction to have made even an approximate estimate of future conditions. In our discussion of materials we will make some attempt to consider predictions in the (*a*) and (*b*) groupings as indicated above.

Material shortages in both war and peace time have emphasized the need for conservation of our resources and the development of new or substitute synthetic materials. Shortages of such simple and important materials as water and iron have begun to affect markedly our planning and economy. Efficient utilization or recyclization of materials into our system of usage may alleviate the shortage but this is not sufficient in many cases, and we must seek substitutes and synthetic products to take the place of diminishing natural resources.

The many directions in which our modern technology has tended to grow and develop make it exceedingly difficult to predict the materials of the future except by extrapolation of recent development. We must, however, definitely eliminate the feeling that still exists in many areas that natural products are superior to synthetic products. In general we have been able to improve on a great many substances which are considered "natural" and there is some difficulty in differentiating between synthetic and processed materials.

We may expect that materials of the future will be gradual improve-

ments of the existing materials through continued research in production or development, or radical departures from our existing material due to shortages or discovery of better substances. We may expect that modern research methods will provide a continuous supply of new materials and that fantastic predictions made now as to future materials will in time to come appear to be ultra-conservative.

As an example of the change of materials, one might consider the changes in optics produced by new lens materials—plastics have provided precision casting with optical surfaces for lenses, prisms and gratings. A recent announcement indicates that synthetic sapphire has been produced in size and quantity sufficient to produce motion picture camera lenses. The sapphire is water clear in appearance, has a high index of refraction and a low dispersion which permits lens production with a minimum of necessary correction for color and lens curvature. Its hardness guarantees a continued lens surface of satisfactory clarity; in fact the finished lens could be cleaned with steel wool with as little abrasion as our present day glass lenses receive from an application of soft lens tissue.

Synthetic mica has recently been successfully produced at the National Bureau of Standards; other laboratories have also indicated work on this and other similar insulating materials. The economy of nations has often been disturbed by new material substitutes—such as the effect of nylon and rayon on Japan, and some consideration must be given to the influence of a synthetic mica or mica substitutes upon the economy of India where natural mica has been one of its principal industries. India has in previous years had its economy disrupted by the development of synthetic indigo and alizarin. We recognize that the perpetuation of the old order of supply and material by propaganda of superiority of natural products over synthetic, as well as by legislation and trade treaties is not conducive to the general world advancement and an acceptance of a change in national economy and industry to conform to progress is often essential.

Our consideration of the materials of the future must be predicated on the present change in materials and an extrapolation along the general direction they are taking. We will briefly consider some of today's material advances in inorganic, metallurgical and organic substances so as to effect this perspective of the future.

Magnesium may be expected to be in a reasonably steady supply for a long period to come, due to methods of production from the nearly limitless quantities of sea water, and in a like manner bromine, which is also extracted from sea water, will be in constant supply. Other materials such as iron and petroleum seem to oscillate in apparent supply as a result of a demand rate which appears to be depleting the reserves on one hand and on the other hand the discovery of new deposits, such as the iron deposits in Labrador and Venezuela, which

change the apparent critical balance of resources and demand. The development of new uses and applications of materials may markedly change the supply condition. Beryllium supplies, for example, were seriously threatened by the sudden demand for beryllium type phosphors in fluorescent light, but as often occurs in such cases, the continued research of scientists provided sufficient or better substitutes which did not use beryllium and the toxic properties of beryllium which had not been seriously considered until this wide commercial application, have together led to almost complete elimination of these phosphors and the conservation of this element for other specialized applications.

GLASS AND SYNTHETIC CRYSTALS

Glasses which are photo-sensitive and electrically conducting have recently been developed. Important progress is also being made in the less obviously significant optical glasses. Glasses composed of the rare earth oxides, phosphates, fluorides, and even sulfides, selenides and other non-oxides are being actively investigated to discover combinations that will afford highly desirable properties such as high refractivity with low dispersivity, or high transmissivities outside of the visible region. Modern fundamental research on the constitution of glass has given extremely valuable assistance to this strictly developmental job.

There is a growing demand for large discs and lenses with very stringent requirements for optical quality. Large windows for supersonic wind tunnels are needed so that accurate observation of shock patterns and flow lines can be made by the "schlieren" and interferometer methods. Large lens elements for aerial photography, photogrammetry and for special astronomical observation are sorely needed. The trend in production is away from the conventional clay-pot melting toward the small continuous tank with non-corrodible refractory lining. In this way contamination of the very pure batch materials is avoided and uniformity of glass composition is assured by adequate stirring of the molten materials during passage through the tank.

Mention has already been made of the production of synthetic sapphire and mica. As often happens, the synthetic production can be controlled or varied so as to produce superior material as compared with the natural product. The synthetic mica has been shown to be superior to natural mica in its resistance to high temperature effects.

Synthetic asbestos will certainly be a product of the near future and the commercial production of crystalline rock salt, sylvite, fluorite, quartz, and thallium halide crystals of considerable size and clarity have opened up new fields of physical research and optics. Synthetic crystals of Rochelle salts and other materials have formed the basis of our controlled frequencies in radio transmission.

Synthetic titanium dioxide crystals, while not as hard as the natural diamond, possess nearly equal brilliance. Their application has princi-

pally been in jewelry, but in view of the easily available raw material it is certain that it will become an important optical material of the future. We may expect many new inorganic combinations in the form of synthetic crystals and amorphous glasses which will have important research and industrial uses in the future.

Barium titanate crystals in thin wafer form show remarkable electrical properties under stress, which have provided the basis for new microphone and record player sensitive elements.

CERAMIC COATINGS

As in other branches of technology, the most spectacular material advances in the field of the non-metallic, inorganic mineral products have been those related to communication, transportation, and ordnance.

In pottery and porcelain, the two notable contributions have been, (1) the development of ceramic capacitors of high-dielectric constant and low power loss for very compact radio and radar installations, and (2) oxide porcelains extremely resistant to high temperatures and thermal shock for use as turbine blades and flame throats in jet and rocket motors. The very remarkable dielectric properties of some of the titanates of the alkaline and rare earths are being utilized for capacitors by an ingenious combination of extremely thin discs, each disc varying slightly in composition so that the whole provides a material with a high dielectric constant over a wide temperature range. A combination of refractory oxides prepared by the National Bureau of Standards consisting of a large percentage of beryllium oxide with smaller amounts of alumina, zirconia and lime showed such promising properties in the laboratory that its fabrication into turbo-jet blades was sponsored by NACA and in full-scale test on a test stand showed by far the greatest potentiality for use of any ceramic blade developed to date.

The increased demands for power in jet, rocket and internal combustion engines have called for operation at higher temperatures. Metals for such installations must not only have the toughness and strength but must also have the high melting point necessary. Unfortunately, the metals available in the requisite quantities necessary, notably molybdenum, are highly susceptible at operating temperatures to oxidation and other forms of corrosion. By research work at the National Bureau of Standards the principle of successful application of a ceramic protective coating has been indicated and the protective coating itself has been successfully developed and applied. The coating is a metal-ceramic combination. During heating to cement the coating to the base metal, the metal powder incorporated in the mixture is welded by diffusion to the base metal, providing a firm and very adherent intermediate layer. An additional all-ceramic outer layer provides additional protection.

LIGHTWEIGHT AND PRESTRESSED CONCRETES

Lightweight concretes are now being made by three different methods. The most widely used method is that of substituting lightweight aggregates for the more common aggregates, sand, gravel, and crushed stone. A lightweight material may also be made by whipping air into mixtures containing surface-active agents such as soaps, resins, or detergents, in an amount usually ranging between 0.001 to 0.002 per cent by weight of the concrete. For structural concretes the optimum amount of the entrained air ranges usually from 3 to 6 per cent of the volume of the concrete. Mixtures of cement and water containing these agents may be used alone or in combination with aggregates. The third method of producing a lightweight concrete is by the introduction of admixtures which react chemically to produce a gas. Powdered metallic aluminum is used most often since it reacts readily with alkalies to produce hydrogen which causes a marked increase in the volume of a cement-water mixture.

Lightweight concretes suitable for use as a load-bearing material usually are made with such lightweight aggregates as expanded clay, shale, slate or blast-furnace slag. These concretes have compressive strengths usually between 1000 and 6000 psi. They weigh one-third to two-thirds as much as dense aggregate concretes and their thermal conductivities are from one-fourth to one-half as much. The use of the air-entraining agents improves the workability and homogeneity of the concrete and increases many fold its resistance to the action of freezing and thawing. Much of the concrete pavement built during the past 10 years was built with aerated concrete.

The use of such lightweight aggregates as perlite and vermiculite in lieu of the heavier aggregates makes possible the production of concretes weighing as little as one-fifth the weight of ordinary concrete and having thermal conductivities less than one-tenth that of dense aggregate concrete.

The development of prestressed concrete resulted from an effort to overcome the basic shortcomings of concrete, *viz.*, low tensile strength, low extensibility, plastic flow under sustained loads and shrinkage due to drying. In prestressed concrete, external forces furnished by the prestressed reinforcement, compress the concrete in those zones where tensile stresses are anticipated; these external forces also overcome the effects of shrinkage and plastic flow by virtue of the prestress in the concrete. Prestressed concrete can thus be regarded as a material quite distinct from ordinary reinforced concrete, since it is an elastic material capable of resisting tension as well as compression. The use of high yield point reinforcement made prestressed concrete possible, since it is now feasible by using high-strength wire as reinforcement to absorb losses of stress due to shrinkage and plastic flow and still leave

sufficient prestress in concrete to maintain compression in the concrete under load.

LEATHER

Many of the recent significant developments in the field of materials have been brought about by the necessity of meeting shortages in those common industrial materials that have been known for so long and used for so many purposes that they are commonly taken for granted. Leather—man's oldest industrial product—is no longer available in quantity adequate to supply the multitudinous purposes for which it has been or might be used. Many of these applications are now being served as well or even better by other materials such as rubber, textiles, paper, or plastics, but there are still applications for which leather is in demand in quantities in excess of the available supply. One of these applications is sole leather currently needed for footwear.

Investigations at the National Bureau of Standards are currently being directed toward alleviating this shortage by impregnating the leather with rubber and related polymers so as to increase markedly the durability of the soles and also to permit the use of grades of leather for soles not hitherto suitable for the purpose. Belly leather, which is not normally suitable for soles because of its loose open structure, can be made into a durable sole by impregnation with rubber. Furthermore, with any leather the flesh side is the more suitable for impregnation by reason of its fibrous structure. This renders it possible to split leather and use the grain side for shoe linings or luggage and yet to make a sole from the remaining flesh side that will greatly outwear an untreated sole made from the entire thickness of the leather. The penetration of water is reduced to about *50* per cent of that of untreated leather; other properties are not greatly altered by the treatment.

Various types of polymers have been used for the treatment of leather with good results including different forms of natural rubber, gutta percha, polybutylmethacrylate, and polyisobutene. The polyisobutene is employed in a 30 to 40 per cent solution in gasoline or toluene. The optimum molecular weight is 50,000 to 100,000; polymers of higher molecular weight will not adequately penetrate the leather while with lower molecular weight the wear is reduced.

FIBERS, DETERGENTS AND TREATING AGENTS

Another instance of the conservation and extension of an important natural product is found in the case of pulp for making paper. Hitherto the pulp from coniferous softwood trees such as spruce, fir, and pine has been used to a much greater extent than the pulp from hardwoods such as birch, beech, gum, poplars, and aspen. The increased use of the hardwoods for pulping is important both because of the growing shortage of softwoods and also because of the economic necessity in

forestry operations of utilizing hardwood trees that are not suitable for lumber.

The pulp from hard wood differs from that from coniferous wood in that the fibers are much shorter and have a structure that makes the paper in which they are incorporated weaker, softer, and more absorbent. The increased utilization of hardwood pulp in the production of paper is made possible by bonding the fibers with resin instead of through fibrillation and gelatinization produced by the conventional long beating. In studies of offset papers at the National Bureau of Standards it was found that offset papers made with 75 per cent of hardwood pulps compare favorably with papers made in the conventional way with the customary combination of equal parts of hardwood and softwood fibers. The resin bonding was accomplished by the addition of melamine-formaldehyde resin in amounts up to 3 per cent. The beating time was one and one-half hours as compared with nine hours in conventional manufacture.

An example of the continued development of fibrous materials is seen in the roofing felt industry where asplund fibers, prepared from wood chips by the defibrator process invented by Arne Asplund of Sweden, are being widely used in the manufacture of roofing felts. These fibers have proven to be a boon to the asphalt-prepared roofing industry, which, though only a little more than half a century old, furnishes approximately ninety per cent of all the roofings sold in this country.

Radical development of new materials in construction, building, and electrical industries meets not only some resistance and opposition from people who like things the way they and their forefathers have had them but also building code and labor interests who resist advances which call for a realignment of ideas and procedure.

The new detergents wet, penetrate and emulsify to a remarkable degree. They have low surface and interfacial tensions and a wider range of these properties than ordinary soaps. Many are salts of sulfated alcohols such as lauryl, cetyl or oleyl, or are salts of sulfonated compounds. They are widely used by industry for textile processing, and in insecticides, cosmetics, and lubricating compounds and for cleaning metals and many other materials.

The development of classes of detergents which are equally operable in hard as well as soft water may affect the whole water-softening industry.

There will certainly be many new types of synthetic fibers to join the recent innovations of nylon, orlon, glass fibers, and rayon to displace or improve our material fiber sources. These will be combined with additives to produce desired wetting, water repellent, air penetration, fire resistant, insect repellent and mold or mildew deterrent properties to improve the appearance and usefulness of the fabric.

SILICONES AND INORGANIC COMPOUNDS

Future materials will undoubtedly involve our expansion of inorganic compounds as plastics, adhesives, fuels, and fibrous materials. The development of new organic compounds may not be paralleled in the inorganic field but relatively important studies will be made in this field. As an example of such substances one might consider the silicones. From academic researches on the chemistry of silicon during 40 years, we have new products with unusual properties called silicones. For example, methylchlorosilanes react with absorbed moisture on surfaces of glass, ceramic materials and textiles to form stable, tenacious water-repellent films. Silicone oils are valuable as lubricants and as hydraulic fluids. They suppress the foaming of petroleum oils. Electrically the silicone oils have very low dielectric losses, and they do not cause rubber to swell. Silicone resins are thermally stable, resistant to oxidation, and good electrical insulators. Silicone rubber popularly called bouncing putty has exceptional thermal stability. It retains its elasticity over the range $-55°$ to 250° C. or higher, is not affected by ozone and has excellent electrical properties.

The non-carbonaceous fuels such as hydrazine (N_2H_4) offer interesting and important possibilities, especially in the rocket propellent field.

The demand for titanium dioxide as a white pigment, now about 200,000 tons a year, is still increasing and its use is effectively relieving the requirements for the scarcer lead pigment in paints. Zirconium dioxide is used as the point material in a new "point" light source which is useful in optical research. Germanium and its derivatives have proven extremely useful in electrical valves as the germanium diode and the germanium triode or transistor. Lithium-aluminum-hydride has opened up a new and important procedure for the reduction of organic compounds and synthesis of new derivatives.

TITANIUM AND METALLURGICAL DEVELOPMENT

Titanium is fourth in abundance among the structural metals, being exceeded only by iron, aluminum, and magnesium. It was long believed to be too brittle to be useful, until its supposed poor qualities were shown to be due to oxygen and nitrogen content. With the development by the Bureau of Mines of a process for producing ductile titanium from its ores, intense interest has arisen in the many possible applications of the pure metal. To a large extent, pure titanium promises to be very useful for many purposes, much work is in progress on the development of titanium-base alloys, some of which might be as superior to titanium for special purposes as stainless steel is to ordinary steel.

The Bureau of Mines has also developed a process for making ductile zirconium. The corrosion resistance of this metal is in general

similar to that of titanium, but zirconium lacks the advantage of unusually light weight. Columbium and tantalum, especially the latter, are even more corrosion resistant than titanium and zirconium. Columbium is still mainly used for alloying steel. A recent special use is columbium nitride as an extremely sensitive bolometer receiver surface. The comparative chemical inertness of tantalum has led to its fabrication into acid-proof chemical plant equipment, skull plates, and surgical wire.

Each advance in our machine-age civilization points the way to further advances, provided better metals or materials can be developed to meet the new performance requirements. The development of the automobile, starting about 1900, initiated thinking along strength-weight and reliability lines, and experience gained in the development of the automobile subsequently made possible the airplane. The development of steels which retained their strength at elevated temperatures resulted in improvements in steam-power installations and in the chemical industry where many reactions proceed more efficiently at temperatures higher than were previously attainable. These uses require improved resistance to oxidation and corrosion as well as increased strength and reliability at high temperatures. At present the peak demand for materials for high temperature service is for gas turbines and jet-propulsion engines. At the other end of the temperature scale, there is a demand for better and more reliable metals and alloys for use at very low temperatures encountered in the mass production of liquid air, in airplane operation at high altitudes, and in transportation in the arctic and polar areas. The demand for new and improved metals and alloys is always intensified by war-time activities.

Future developments will produce metals and alloys with higher strengths and better resistance to creep, fatigue, oxidation, and corrosion. Improvements are expected in stainless and alloy steels, in the lightweight metals, aluminum and magnesium and their alloys, in currently available "super alloys" and in protective coatings for high-temperature service and corrosion resistance.

ORGANIC COMPOUNDS

Organic chemicals, the compounds of carbon and hydrogen, oxygen, halogens, or other elements, will without doubt continue to supply our major variety of new synthetic compounds of the future; although the advances in these compounds in the past 125 years have led us now to accept the new and fantastic organic materials of today as commonplace and expected. The founding of the Faraday Society in 1825 almost coincides with the accepted date of the founding of Organic Chemistry as a separate science. (Wohler's synthesis of urea in 1828.) The enormous strides to be made in this field of science in the future will undoubtedly be as significant and spectacular as those of the past

century and a quarter; although these advances may be less impressive due to the present highly developed position of the science.

The limitless possibilities in this field are exemplified by the development in recent years of the commercial production of an extremely simple organic compound, ethylene oxide, (CH_2—CH_2, O). From this one substance are produced ethylene and diethylene glycols and their mono- and diethers, polyethylene glycols, glycol acetates, ethanolamines, and their substitution products. Solvents, plastics, water-soluble waxes, pharmaceuticals, fumigants, and many other products are now made from ethylene oxide and are available in carload lots.

New drugs, foods, dyes, plastics, perfumes, paints, lubricants, refrigerants, and many other substances will continue to flow onto the commercial and research markets in the future in increasing amounts.

GENERAL

The recognition of new materials as an important news item in science and industry is apparent in the "New Materials" sections which appear in many of our current technical and trade journals. Among such listings are the "New Materials" section in the *Review of Scientific Instruments*, the "New Chemicals and Specialties" section in the *Chemical and Engineering News*, the "New Products and Materials" section in *Chemical Engineering*.

CONCLUSION

Greater emphasis in the future must be placed on efficient conversion of energy sources, which as Dr. Wiley indicated some 50 years ago would be principally our energy from the sun.

We may expect that the use of radiant energy with the production of carbohydrates may be the principal source of our heating fuels, foods, and combustion engine fuels. For example, it has been calculated that the anaerobic fermentation of the corn stalk material grown within a 10-mile radius of one of our smaller mid-west communities of some 20,000 population would supply the essential heat and power requirements of such a community throughout the year. We may expect that as our supplies of coal and petroleum diminish, greater use will be made of potential water, wind, and tidal power to compensate for the reduced supply of those materials which are largely converted into mechanical energy.

The fantastic fields opened in the application of atomic energy principles may lead to elemental syntheses and energy effects which at the moment are unpredictable by the non-atomic scientist but certainly must be considered in any future material prediction. The use of both atomic and solar energy in the production of useful materials will always

be an important problem. It is certainly within the realm of possibility that we may in the future synthetically produce our organic compounds through commercial chemical reactions involving radiant energy and chlorophyll-like catalysts together with simple raw or elemental materials. Foods and drugs will always be a problem of research in the future with a continued production of new substances to increase our span of life, relieve suffering and increase our pleasure.

On the average, material resources should not seriously concern us in the future although minor shortages may cause us to change our mode of living in some aspects. Actually only about 20 per cent of the earth's surface has been searched for its resources and vast stores below the surface as well as under the sea have not been tapped to any degree, with the possible exception of oil wells, which have barely encroached beyond the shore line into the vast ocean area.

We can certainly expect that from the trend of new development of materials that just as new or original innovations will continue in the future. The change in availability of the common materials will undoubtedly be the greatest influence in the future developments of new materials. The scarcity of water, iron and many other common materials may result in new methods of conservation recovery and suitable substitutes.

Synthetic materials may be expected to promote and accelerate the production of natural materials. The use of synthetic insecticides, plant hormones, anti-virus compounds and fertilizers and the accelerated and amplified production of natural products together with a program of conservation, utilization of waste and by-products and development of new substitutes should certainly solve the material supply problems of the near and even distant future.

BETTER NUTRITION FOR MORE PEOPLE

BY

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Nutrition has three major meanings. It is the name of a science which has developed through the union of chemistry and physiology. It stands also for conditions and processes in the body. And moreover it means the furnishing of nutriment. The title to which this paper is committed thus carries the implication that through the further development of the science of nutrition and its application in food management, we propose not only to feed a growing population but, further, to provide a better food supply per person, so that a superior nutritional status shall be maintained in a larger number of people. For, as Conant has cogently pointed out, the world of today is taking on a new sense of opportunity and responsibility for the better human use of its resources.

THE PROBLEM OF ENOUGH OF THE RIGHT KINDS OF FOOD

Foremost among the material needs of the human family is enough of the right kinds of food. Economics tends to a four-fold view of the requisites for such a project: first, land; second, labor; third, capital; fourth, management, which last in this case calls for managerial efficiency in the processing, distribution, and use of food.

Obviously the most direct impact of the new science of nutrition is upon food management. It is with this that the present paper is chiefly concerned. Recently, however, much has been said and written in dread of the normal growth of population lest it come to press upon the food supply. It therefore seems proper at this point to say that this paper is written in the light of long study of the requisites for food production and use, so that (while space does not permit any attempt to assemble all the evidence here), we can speak with considerable confidence in the scientific soundness of the view that our *present and potential food production resources* are amply sufficient for any such demand upon the food supply as the best scientific judgment can foresee.

Much new land can be brought into cultivation as rapidly as there is sufficient market for what it will produce. And practically all land can be made more productive by increased attention to its cultivation and fertilization as well as by use of more productive varieties of animals and plants. Experts have estimated that if the land of the United States were in Europe, twice as many of its acres would be cultivated as now are under cultivation. Of the earth's entire land surface, it is

estimated that 50 per cent could be cultivated but only 7 per cent now are under cultivation. Probably some agriculturists would say that only a little over the 7 per cent now cultivated is "suitable," but this would be counting as suitable only such land as would promptly yield a money profit in competition with the land already under cultivation. But as larger populations make a larger market for crops, more land will become profitable to cultivate. There is also the growing probability that public funds may in future be used to make more land cultivable than is now in cultivation. For just as public funds now are used to provide populations with water supplies, so also they may be used to increase the supplies of such foods as are especially important to health and efficiency.

The normal evolution of agriculture with its increasing prevalence of dairy farming will provide a superior grade of employment for increased numbers of workers. Much capital is seeking investment and as more capital is made available, land and labor both can become more efficient.

Probably land, labor, and capital will so interact that the limiting factor in the problem of better nutrition will be none of those so much as it will lie in the people as food consumers.

TRENDS OF FOOD CONSUMPTION IN THE UNITED STATES, 1909–48

In August, 1949, the U. S. Department of Agriculture issued its Miscellaneous Publication No. 691, "Consumption of Food in the United States, 1909–48," the most comprehensive and detailed report upon this subject. These official estimates cover each year of the forty-year period, 1909–48. From these data have been taken the figures for 1909 and 1948 to show the trends in consumption of nine typical foods or food groups, here shown in Table I.

TABLE I. *Trends in Consumption of Types of Food, 1909–1948, per Person per Year in the United States.*

Type of Food		1909	1948	1948 as % of 1909
Fresh citrus fruit	lb.	15.3	51.0	333
Dry beans, peas, nuts	lb.	11.0	16.0	145
Leafy, green and yellow vegetables	lb.	68.3	90.3	132
Total milk equivalent	qt.	194.	249.	128
Sugars and syrups	lb.	84.	106.	126
Fats and oils	lb.	59.	65.	110
Meats, fish, poultry, eggs	lb.	196.	205.	105
Grain products	lb.	291.	171.	62
Potatoes and sweet-potatoes	lb.	201.9	112.4	56

Although food habits are, in general, slow to change, the data of Table I show that our consumption of some foods rose, and of others fell, very decidedly during the 40-year period, 1909–48. Some changes are, and others are not, in the direction of the teachings of the newer

knowledge of nutrition: evidence both of response to education and of need for more (or more effective) teaching. That the total effect of all the changes (not of each) was to leave the energy and protein values practically unchanged while increasing the calcium, iron, and vitamin values consumed per person in the United States is shown by Table II.

TABLE II. *"Nutrients Available for Consumption" and Recommended Allowances, per Person per Day in the United States.*

		In U. S. Food Supply of Years			Recommended Allowances
		1909	1930	1948	1948
Food energy	Calories	3480	3460	3240	2600
Protein	gms.	101	98	96	65
Calcium	gms.	0.85	0.89	1.04	1.06
Iron	mgm.	15.0	14.1	17.0	11.6
Vitamin A value	I.U.*	7600	7500	8700	4600
Thiamine	mgm.	1.78	1.66	2.05	1.24
Riboflavin	mgm.	1.88	1.88	2.35	1.63
Niacin	mgm.	17.8	15.8	19.5	12.4
Ascorbic acid	mgm.	105.	100.	123.	70.

* I.U. = International Units, which are also the Units of the U. S. Pharmacopoeia.

It is evident from Table II that, except with respect to calcium, the habitual food consumption in the United States carries very generous margins of safety over even the liberal Recommended Allowances of the National Research Council. We could make much larger adjustments in our food consumption than were called-for in either the First or Second World War. There is, however, another direction in which we should make adjustments. Peace or war, we should have better distribution of our food supply and make, as we can if we sufficiently *will*, Freedom from Want, a reality.

KINDS AND AMOUNTS OF FOODS AND OF NUTRIENTS

In the early years of the twentieth century the descriptive chemistry of foods had outgrown the understanding of their functions in nutrition. The chemist could analyze most foods with as near an approach to one hundred per cent as he could analyze most other natural things; but could not maintain normal nutrition by feeding the food constituents which his analyses revealed. As the function of food is to nourish, it became obvious that more insight was needed; and this was sought by use of different types of research: structural organic chemistry for fuller knowledge of the molecular constitution of the substances involved in nutrition; physical chemistry both for concepts and instrumentation; and the evolution of laboratory animal colonies into new kinds of instruments of precision.

The extension of scope and increase of precision in research upon foods and nutrition soon began to be rewarded by a rapid series of discoveries of substances previously unknown or neglected but which

by the newer feeding methods were found to be essential to the processes of nutrition, and keys to previously baffling diseases.

What with the vitamins, the nutritionally essential amino acids, fatty acids, and mineral elements, some forty-odd *factors* (elements, substances, or groups of closely related substances, as the case may be) are now known to perform specific functions in the cure and prevention of diseases, and the promotion of health and efficiency. One of these, vitamin D or the vitamins D, is (or are) usually provided from sources other than food, while nine factors (see Table II) are now regularly taken into account in food and nutrition planning. It is judged that under such conditions as are likely to be met, a food supply which has been found by quantitative investigation to provide ample amounts of the above factors may, with scientific soundness, be trusted to furnish enough of the other essential factors without further investigation. At least, we consider this a sound working hypothesis for the ordinary purposes of the present day, though it may be modified in detail as our knowledge grows through further research.

During the Second World War the National Research Council re-established its Committee on Food and Nutrition, afterward renamed Food and Nutrition Board, and called upon it to formulate standards of adequacy for human nutrition and food supplies. After several months of careful study and discussion there resulted a table of Recommended Dietary Allowances of each *of* the ten factors mentioned above and *for* each of 17 age, sex, and activity groups of the population, with provision also for taking account of differences in size among people of like age, sex, and occupation.

For our present purpose we may use these Recommendations in the simplified form of per capita allowances for comparison with per capita data of food consumption.

The food supply of the United States is of higher and better-balanced nutritive value now than formerly because there is more guidance of food habits by present-day nutritional knowledge and because a large proportion of the flour, bread, and breakfast cereals consumed is "enriched" (fortified) with iron, thiamine, riboflavin, and niacin.

POTENTIALITIES OF NUTRITIONALLY GUIDED FOOD MANAGEMENT

The managerial aspects of the general problem, with which this paper deals, extend not only through food production, processing, and marketing but into the *use of food* as well. Every consumer of food, whether realizing it or not, is influencing the efficiency with which each year's food crops are used, and also the decisions as to what production shall be planned for the following season, year, or years.

Distribution of our nation's food supply among its people, according to present knowledge of their nutritional needs, would mean that we all would be well fed. Whether it would ensure *optimal* (that is, literally,

the *best possible*) use of the nation's food supply and resources for food production involves consideration of further facts.

One of these facts is that with some but not all nutrients there are wide differences between the minimal-adequate ("rock bottom") requirement which is strictly needed for prevention of demonstrable deficiency; and the more liberal allowance which may help in the attainment and maintenance of optimal health and efficiency.

Differences between minimal-adequate and optimal intakes of ascorbic acid (vitamin C) are illustrated in the work of C. G. King who finds that 0.5 milligram of vitamin C protects a young guineapig from "classical" scurvy; but promotion of tooth formation and wound healing require about 3 milligrams, and maximal phosphatase activity in wounds during the course of healing is not achieved until the intake is approximately 5 milligrams a day, or ten times the minimum that affords protection from scurvy. Neither is maximal resistance against injury by bacterial toxins reached until comparable high levels are supplied. Thus there is a very wide scope for benefits to be gained through increased intakes even up to about 10-fold the "strictly needed."

As with vitamin C, so also with *vitamin A*, although these are entirely different substances both in chemical nature and in nutritional function. Several years of careful research have firmly established the fact that there are large "areas," above the level of actual (minimal) need, where successive increases of intake of the vitamin yield correspondingly increased benefit to the life history.

For instance, in the nutrition laboratory of the Columbia University Department of Chemistry we have repeatedly had rat families thriving in the 70th–73rd generation nourished exclusively upon what for convenience we may here call Diet A.[1] Thus in an unprecedentedly rigorous test the diet shows itself adequate for growth, health, longevity, reproduction, and lactation generation after generation and all within the normal range. But this intake level does not build up a significant reserve store. If from that starting point and with ample controls, a part of the animals have the vitamin A content of their food approximately doubled, they live longer; and then with another doubling of the vitamin A intake the average length of life is again increased. At this vitamin A intake level of about four-fold the minimal-adequate, the males lived 10.4 per cent, and the females 12.1 per cent, longer, and showed higher health and performance records at every stage of their improved life histories.

In similar experiments with different levels of intake of calcium as the sole variable factor, it was found that doubling an initial minimal-adequate level improved the life history but did not suffice for optimal results, which, however, appeared to be reached when the calcium level

[1] In the research records it is Laboratory Diet 16. Undoubtedly this diet meets all nutritional needs of successive generations indefinitely.

TABLE III. *Comparison of Results of Feeding Diets A and B (See Text) to Parallel Experimental Animals (Rats).*[*]

	DIET A		DIET B		
	(No. of Cases)	Mean ± P.E.[a]	(No. of Cases)	Mean ± P.E.[a]	Difference with its P.E.[a]
Gain in body weight, 28th to 56th day, in grams					
Females	(200)	37.0 ± 0.8	(200)	62.4 ± 0.6	25.4 ± 0.9
Males	(200)	44.3 ± 0.9	(200)	82.9 ± 0.8	38.6 ± 1.2
Gain in body weight per 1000 calories of food, 5th–8th weeks, in grams	(100)[b]	60.5 ± 0.7	(100)[b]	77.0 ± 0.6	16.5 ± 1.0
Age at birth of first young, in days	(200)	155 ± 1.5	(200)	112 ± 1.1	43 ± 1.9
Duration of reproductive life (females), in days	(115)	186 ± 7.7	(129)	322 ± 8.9	136 ± 11.7
Length of life, in days					
Females	(196)	603 ± 8.0	(163)	669 ± 7.8	66 ± 11.2
Males	(135)	571 ± 8.0	(124)	635 ± 8.5	64 ± 11.7
Number of young reared per female	(115)	5.8 ± 0.5	(129)	18.1 ± 0.8	12.3 ± 0.9
Average weight of young at 28 days, in grams	(673)	34.0 ± 0.5	(2337)	40.3 ± 0.3	6.3 ± 0.6

[*] Published with permission of the Columbia University Press.
[a] The ± precision measure following a *mean* or a *difference* between means is its "classical" Probable Error (P.E.).
[b] Averaged by "lots" of five animals each (100 lots on each diet). On all other lines the figure in parenthesis means number of individuals.

was raised to four-fold the minimal-adequate level. At this four-fold level (and perhaps at somewhat less liberal levels if the diet is sufficiently well constituted in other respects) the length of adult life was increased 11.5 per cent in males, and 13.8 per cent in females. And here again the level of health and performance was improved in each of the above mentioned criteria of the longer lease of healthier life.

Gains of 10 per cent in length of adult life in both sexes, with improved records of performance in every segment of the extended life cycle, were also realized in experiments in which the above described Diet A was improved in terms of its natural foods by increasing the proportion of milk in an already adequate wheat-and-milk diet (Table III).

Special interest has attached to the comparison of our Diets A and B. In this, the starting point or basal diet, a mixture of natural foods here called Diet A, was found *adequate;* while under otherwise identical conditions a food supply containing a higher proportion of milk (*Diet B*) showed itself *better*. In these experiments parallel lots or families of experimental animals, each consisting of three female and two male rats, were started simultaneously on each of the two diets at the age of 28 days (conventionally considered end of infancy in the rat). They continued on their respective diets till natural death. The results are summarized quantitatively in Table III.

These data show clearly that both the rate of growth and its efficiency (gain of body weight per 1000 calories of food consumed) were increased by the increased proportion of milk in the diet. Likewise development was expedited, a larger number of offspring were produced, and a higher proportion of them reared, both parents and offspring showed greater adult vitality, senility was deferred, lives were longer, and with a smaller proportion of days of "dependency." Exceptional care was given to completeness of control so that there is no room for doubt that all these gains in the life histories of the experimental animals and their offspring were strictly due to the better nutrition resulting from a change in the proportions of the natural foods in an already adequate diet.

The increased longevity amounted to ten per cent of the adult life expectation, equivalent to giving us (humans) an adult life-expectation of 77 years instead of the traditional 70.

In previous studies of the length of life, methods had been used which enabled the investigators to correlate longevity with heredity and with nothing else. This resulted in a widespread error, of assuming that no such correlation would be found, when really the failure to find it was because of the limitations of the research methods then used. It was temptingly easy to teach that "while one may shorten his life in many ways the only way to lengthen it is by the selection of a longer-lived ancestry." And again it was mistakenly taught that "while we can add life to our days we cannot add days to our lives."

Thus the finding that already normal health and longevity can be improved by nutritionally guided use of food had to overcome an actively prevalent erroneous view to the contrary.

Because of the importance of this point both in pure science and to give to public health the full benefits of the new knowledge of nutrition, the experiments were made repeatedly over several years. The numbers of experiments on this point were such, and results so consistent, as to establish the finding with 100-times the degree of statistical convincingness which careful scientists deem to justify the characterization of a finding as "undoubtedly" significant and conclusive.

Significant also is the fact that in each of our three main researches in which improvement of an already adequate diet has increased the length of life, the so-called useful life (the time between the attainment of maturity and the onset of old age) was increased in even greater ratio than the life cycle as a whole.

SOME PRACTICAL APPLICATIONS

With nutrition now scientifically recognized as "undoubtedly" carrying such important potentialities for higher health and longer life, the opportunity and responsibility of realizing these potentialities, in our own lives and those of others, is greatly accentuated. Every consumer of food is influencing the decisions as to what foods shall be produced and how much of each. Consumers thus function as a "management" factor in the enterprise of providing a nutritionally better food supply.

Hence more keenly now than ever before, people are coming to *want* the better life whose first essential is nutritional well-being. The world wants each nation to develop according to its own cultural genius; and all in a world atmosphere of social justice. To this end we should cultivate a scientifically sound discrimination between differences of food habit which are really due to cultural *choice* and those which have been forced by economic disparities. How far is it due to choice and how far to economic limitation that most other countries support from 2 to 6 times as many people per 100 acres of comparable land, as do we in the United States? Probably the two chief factors in this difference are: (1) that the peoples of the older civilizations give more *human* effort per acre to the care of their crop land; and (2) that they bring much more of the crops directly into human consumption, while we feed more, especially of the grain crops, to meat animals. Competition among consumers for grain-fed meats means high prices for them, which tends to draw an undue proportion of the grain crop into production of meat as contrasted with bread and milk. The Food and Agriculture Organization of the United Nations has emphasized the fact that it takes about seven "original calories," as of grain crops, to

produce one calorie when fed to farm animals; but to put all farm animals into one category in this way is ambiguous because milk animals bring so much more into human nutrition than meat animals do. And beside its relative economy from the viewpoint of calories, milk is the cheapest source of animal protein and the outstanding food source of calcium and of riboflavin. Of course both milk and meat contribute other nutrients which space does not permit us even to enumerate here. On the whole milk cows should be given high priority of claim upon the grain crop over all the meat animals, with egg production ranking somewhere between.

The question how much food our population needs for full health may be answered nutritionally on either of two plans: (1) in terms of representative nutrients as in the National Research Council's table of Recommended Allowances and its accompanying text, or (2) in terms of foods of specified groups or types. Using this latter plan, Senators Aiken and LaFollette suggested a few years ago that every American, for the sake of his health (and social justice) be assured the equivalent of the following per capita food allotment each week.

According to the national food allotment bill of Senators Aiken and LaFollette, the standard would be as in Table IV.

TABLE IV. *Proposed Weekly Allotment Per Person (Senate Bill of Aiken and LaFollette).*

Milk	5 quarts
Potatoes, sweetpotatoes	4 pounds
Dry beans, peas, nuts	8 ounces
Tomatoes, citrus fruits	1 pound, 8 ounces
Green and yellow vegetables	1 pound, 8 ounces
Other vegetables and fruits	2 pounds, 5 ounces
Eggs	4 (number of eggs)
Meat, poultry, fish	1 pound, 8 ounces
Flour and cereals	4 pounds, 7 ounces
Fats and oils	14 ounces
Sugars, sirups, preserves	12 ounces

As was implied at the beginning, the invitation to write this paper was accepted because of the conviction that a right use of food and of resources for food production, under the guidance of our new knowledge of nutrition, enables us, if we sufficiently *will*, to provide better nutrition for larger numbers of people. As there are dozens of essential nutrients, and hundreds of foods to furnish them, the limit of space forbids detailed recital of facts about foods. Rather we must confine ourselves here to *general* facts or *principles* which hold good for whole groups or types of food, and our generalizations about food problems.

(1) It is well to remember from first to last, that: *How to bring the benefits of the new knowledge of nutrition to as many people as possible and as promptly as may be is both an economic and an educational problem.*

(2) We have, however, much more definite and dependable knowledge than was available a generation ago, as to food values and nutritional needs. Details may continue to be debated; but *in the large* man now knows, as never before, what foods in what amounts will adequately nourish an individual, a given family, or a given population.

(3) It has been found that "adequate" nutrition and "normal" health have different degrees of flexibility with different nutrients or nutritional factors. In the cases of ascorbic acid, vitamin A, and calcium, "enough" is *not* "as good as a feast." For, at levels of intake above those of minimal adequacy, increasing the feeding of vitamin A or C or of calcium results in improvement of the already normal life history, up to intake levels more than twice those of minimal adequacy.

(4) Both for our own better nutrition and in order to lessen the consumer demand for foods in need of more equitable distribution, we should strive to give higher places in our dietaries, food budgets, and production planning, to fruits, vegetables (especially the green and yellow), and to milk and its products other than butter.

(5) With "protective foods" thus more amply provided, we consumers of more than average purchasing power should be willing to refrain from such active competition as at present for foods which usually are highly prized but too high-priced to get equitable distribution hitherto. In Western Europe and North America this will usually mean one or more of the three food groups: sugars and sweets, fats and oils, and grain-fed meats.

(6) It may be necessary to educate people to the newly discovered facts of the great influence of food, through nutrition, upon health and efficiency. As the preceding generation came to see that it is not "too paternalistic" to invest public funds in public health through better water supplies, so we are now learning the reasonableness of investing public money in the increased production of those foods of which a larger consumption is especially beneficial to health and efficiency; and thus also in social justice and good will as such policies are seen to bring, to an ever increasing proportion of our people, such higher health and longer life, with enhanced opportunity for achievement and satisfaction in life, as hitherto have been enjoyed only by the most fortunate few.

With consumers interesting themselves steadily in these six general principles, they will be setting up and maintaining such trends in the production, distribution, and use of food as will afford ever better nutrition for more people.

BASIC STANDARDS IN SCIENCE

BY

E. U. CONDON

National Bureau of Standards

The importance of basic standards of measurement is determined by the role of measurement in both science and technology. Lord Kelvin's remark, that a thing is very poorly understood until it has been measured, has succinctly characterized that role, for in the last analysis all knowledge in the physical sciences depends on measurement.

Even theory depends on measurement, for theory is the synthesis of observed and measured phenomena into a coherent and logical system of thought which agrees with the behavior of known events and which can predict unsuspected events. These behaviors and predictions are ascertained and confirmed through measurement.

The basic standards of science are primarily concerned with precision measurement in the physical sciences, but they also establish the foundation for all industrial and commercial measurements. These measurements are controlled by various secondary standards, used in laboratories and industry, which are obtained from the basic standards of mass, length, and time, or from the derived standards in such fields as electricity, optics, and radiation physics.

As they have developed, the sciences have demanded standards of increasingly greater precision, and the science of measurement—one of the oldest technical activities of man—has shown a continued advance. Long before Archimedes worked out the laws of equilibrium, man had weighed matter and counted objects. During those early, technically crude years, man undoubtedly had considerable practical knowledge and intuitional awareness of the principles of such measurement, but it was Archimedes who synthesized and presented this knowledge as a definite and coherent body of knowledge. Innovations between the time of Archimedes and Galileo were relatively few and unimportant. There were not many things to be measured: size, weight, and number were required, but the degree of precision was not great and the ancient methods were largely adequate.

Advances in the physical sciences after the Renaissance and the growth of a machine technology, however, made the development of measurement as a science necessary and inevitable. The manufacture of machine goods and the need for interchangeability of parts in mass production, for example, required increasingly closer tolerances. Science itself has rested, even in most of its theoretical manifestations, on experimental data attainable only by sophisticated tools and methods of

measurement. Thus, one of the foundations—perhaps the principal one—of our science and technology, which determine the very nature of our civilization, is measurement.

The term "standards" often has a connotation of quality, in the general sense meant by consumers of manufactured goods. Such "consumer standards" are important, but they represent only one aspect of the broader subject, on which they ultimately depend, for standards of measurement in science and then in technology are prerequisites to standards in the field of consumer goods.

Stated broadly, standards, whether in science, technology, or commerce, are concerned with determinations of quantities in the most general sense. Even determination of quality—again, in the most general sense—is a matter of quantity. Thus, the relative performance of two engines depends on the comparison of numerical quantities such as size, weight, fuel consumption, useful delivered energy; and even cost is evaluated in terms of numbers whose magnitudes depend on the nature of the materials used while the materials themselves are chosen on the basis of their properties which, in turn, are determined by measurements.

Thus, measurement is the cornerstone of all standards, whether we are dealing with scientific standards or with technologic standards established for manufacture and commerce. For this reason, Lord Kelvin's statement has a significance far beyond that in pure science, with which he was concerned, embracing as it does all technology and commerce.

The wide-spread use of the term "standards" in science, engineering, and in the field of consumer goods has led to confusion as to the meaning of the word in its various applications. Clearly, the basic standards of science, while establishing the foundation for any standards which either directly or indirectly depend upon the measurement of any quantity, are distinct from engineering and commodity standards having to do with specifications and quality.

Speaking broadly, standards are usually physical things representing units of measurement; one can thus compare other things with the standards, and with their aid intercompare other things; the object is clearly uniformity in measurement. The basic standards are two-fold. The primary standards are those of mass, length, and time. The derived standards, which are primary in their own fields, are those of measurement in electricity, optics, thermometry, radiation physics, etc. These primary and derived standards, in the custody of the National Bureau of Standards for this country, constitute the field of basic standards; from them are obtained the secondary standards—close duplicates of the national primary standards—which are used by laboratories, industries, and universities.

Length. The national primary standard of length is the platinum-

iridium meter bar No. 27, whose use is restricted to comparisons with working standards of the National Bureau of Standards. The principal working standard is the companion meter bar, No. 21. Related to the national standard of length are the following standards: Fifteen end standards, 10 cm. in length and 2 cm. in cross section, made of clear fused quartz: these are used to calibrate such secondary end standards as the master precision gage blocks of industry. Three standard plane surfaces, each 28 cm. long and about 4 cm. thick; one surface of each is a true plane within one-hundredth of a fringe (0.25×10^{-6} cm). A standard of angular measure, which is a special comparator provided with four fixed micrometer microscopes spaced 90 degrees around the central rotating table carrying the circle. Circles 9 in. in diameter have been graduated by the Bureau to 5 seconds of arc, with no line displaced from its correct position by more than a micron.

The national standard of wavelength measurements has been a cadmium source of red radiation. Recent work at the National Bureau of Standards has resulted in what appears to be an ultimate standard of length in the form of the green radiation of mercury 198, discussed below.

Mass. The national standard of mass is a platinum-iridium cylinder known as the prototype kilogram No. 20. Two other standard kilograms, one of platinum-iridium, the other of pure platinum, are used as working standards. There is no standard of capacity, and the unit of capacity is established by weighing: the liter is defined as the volume occupied by a kilogram of water at its maximum density. The founders of the metric system had intended this volume to be 1000 cc., but the most recent values indicate a larger volume. Measurements in milliliters give 1.000028 cc. as the volume of a milliliter, and in precise measurements the unit of volume must be specified.

Time. The standard of time is determined by the mean solar day, and the material standard is the earth itself. Time signals from the U. S. Naval Observatories, based on astronomic observations and calculations, provide the basis for checking time. The national standard of frequency, however, is a set of ten quartz oscillators at the National Bureau of Standards, which are checked against the astronomic data. Standard frequencies, derived from these crystal oscillators, are broadcast continuously by the Bureau over radio stations WWV (Beltsville, Md.) and WWVH (Hawaii), as well as standard time signals and highly accurate intervals of time. Recent developments at the National Bureau of Standards have resulted in the development of atomic clocks, promising an invariant standard of time (discussed below).

The national standards listed below are called derived standards in that they depend, with one possible exception, upon the preceding basic standards.

Electricity. The national working standard of electrical resistance is a group of ten one-ohm manganin coils. The national working stand-

ard of electromotive force is a group of 26 saturated Weston cells. The values assigned to these coils and cells are checked at relatively long intervals by protracted painstaking experiments which serve to derive the absolute units of resistance and of electromotive force from the primary units of length, mass, and time.

Photometry. The standard of brightness is defined as the intensity of radiation from the interior of a blackbody at the temperature of pure platinum at its freezing point. A blackbody provides a means for getting a psychophysical standard of intensity or brightness, and thoria crucible blackbodies were developed by the Bureau for this purpose. A set of incandescent lamps, calibrated for candlepower and luminous flux against these blackbodies, constitutes the effective national primary standard of candlepower. Close duplicates of the lamps in this set are used by the Bureau as regular working standards.

The effective national standard of radiant flux consists of a set of incandescent, carbon-filament lamp bulbs. Radiant flux is defined as the rate of flow of radiant energy. The flux per unit area emanating from a black body at a given temperature can be determined at the given temperature by calculation. Instrumental measurement of the flux provides a means of calibrating the physical standards.

Thermometry. The international temperature scale provides a basis on which numbers are assigned to temperatures. The definitions of this scale establish fixed points, such as the ice and steam points, to be used in the primary calibration of the standard temperature-measuring instruments, platinum resistance thermometers, platinum vs platinum-rhodium thermocouples, and optical pyrometers. The National Bureau of Standards, by maintaining the fixed points, provides primary calibrations of the standard instruments and, using a group of primary standards, provides secondary calibrations of many of the common temperature-measuring instruments such as liquid-in-glass thermometers.

Radiation Physics. The national standard of X-radiation measurement is a special free-air, guarded-field ionization chamber. The national standard of radium consists of a set of three specimens containing a known amount of radium element. The national standard of neutron radiation consists of a beryllium sphere containing radium whose gamma radiations eject neutrons from the sphere.

The development and establishment of standards of measurement is a continuing process for at least two reasons: First, our knowledge in so-called known fields increases with continued research in other fields and it becomes not only possible but necessary to increase the precision of our measurements. Second, new fields open up, and these require new standards and methods of measurement.

The field of length measurement affords an example of continuous development of standards. Toward the end of the eighteenth century, the meter end standard was constructed. This was a length of rather high precision, but it is difficult to compare something of unknown length

with an end standard. In 1889 platinum-iridium bars were constructed as line standards, and the meter was established as the distance between two lines drawn on the bars. The precision of these standards is obviously related to the nature of the lines, and in such fields as spectroscopy the standard meter is a relatively gross reference. The wavelength of the red line of cadmium became the standard for precise measurement in spectroscopy.

However, even the cadmium standard has serious disadvantages. First, a fine structure in the red radiation prevents the line from being as sharp as desirable and thus limits the precision. Second, the lamp producing the standard line requires heating in a furnace, which introduces an unwanted broadening of the spectral line.

Work in this field was therefore continued at the National Bureau of Standards, and shortly before the war it became evident that a new standard of length was possible, utilizing the wavelength of green radiation of mercury 198. Here research in atomic physics made the new development possible. It had long been realized that the green line of mercury would have marked advantages for this purpose, but natural mercury consists of a mixture of seven isotopes, having atomic masses of 196, 198, 199, 200, 201, 202, and 204. This isotopic composition results in a broadness and structure of the green line of natural mercury which make it unsatisfactory for precision work.

The objective was to isolate a single isotope, but this could not be achieved by a practical separation process. Advances in nuclear physics, however, permitted the transmutation of gold (Au-197) into mercury 198 (Hg-198) by neutron bombardment. This was done and the new standard developed by the National Bureau of Standards has several advantages: reproducibility, convenience of maintenance, sharpness of the wavelength, and intensity of the spectral line.

In addition to this continued development of standards of length, to meet the needs of science and technology for greater precision, we may consider the development of new standards in new fields. The fields of atomic energy and radio propagation are typical of such fields.

The activity of the National Bureau of Standards in the field of research, measurement, and standardization in atomic and nuclear physics extends back to the early years of the century, when the primary standard of radium, prepared by Mme. Curie, entered the custody of the Bureau. The advances in the field of atomic and nuclear measurements call for the establishment of new techniques, instruments, and standards of measurement; safety provisions for workers and consumers; standard samples for calibration purposes; and test and evaluation methods. During recent years, for example, accurate determinations have been made of the energies of beta and gamma radiations from radioactive iodine 131; the development of cobalt 60 gamma ray standards was successfully completed; research has been in progress on standards for sodium 22 and carbon 14; and construction was completed of a neutron

standard which will serve as a reference unit of neutron intensity for intercomparison of neutron measurements.

The field of radio propagation may be cited as another illustration of the need for the development of new standards. Prior to the war the development of standards, instruments, and techniques of measurement had been progressing into the rather higher frequencies that FM radio and television were entering. Wartime developments in radar, however, brought about a thousand-fold extension of the radio-frequency spectrum. The solution of a large variety of problems in the field of scientific standards is essential to industrial and economic utilization of the expanded radio space, and the National Bureau of Standards has extended its research and development in a field which a few years ago was considered somewhat static.

The trends in this field of fundamental standards can be summarized rather briefly. Continued research and development are required in connection with what we might call the established standards because science and technology call for greater precision as they progress. In many instances, this type of work is related more to improved instruments and methods of measurement rather than new standards. The number of derived standards will continue to increase with the needs of primary standards in special fields. This will be particularly true in new fields—such as atomic and nuclear physics—while an extension of existing standards will continue to be necessary in other fields—for example, the higher radio frequencies.

Perhaps the most revolutionary development which is now underway, however, is that related to the basic standards of mass, length, and time. The ideal standards in these fields would be ones which would be invariant with time, readily reproducible, and readily adaptable to precise measurement. The Bureau's development of mercury 198 as a standard of length satisfies these conditions: the standard depends on the atomic nature of matter, and if a particular standard or all standards of this kind were destroyed, they could be reproduced. Another Bureau development—that of atomic clocks—provides for a standard of time similar in its inherent nature: one clock depends on the vibration of the atoms in the ammonia molecule, another on a beam of cesium atoms. At the same time, the recent absolute determination of the gyromagnetic ratio of the proton, at the Bureau, provides a possible third fundamental standard. Moreover, it may be possible, some time in the future, to derive both time and length standards from the spectrum line of the atoms or molecules of the same element.

These developments enable us, for the first time, to consider seriously the possibility of establishing a complete set of primary atomic standards. This proposal has already been made by members of the Bureau's staff, and it appears reasonable that in the course of coming years it will be possible to adopt new standards, atomic in nature.

FUTURE DEVELOPMENTS IN TRANSPORTATION

BY

CHARLES F. KETTERING

General Motors Corporation

In considering future developments in the field of transportation, it is only natural to focus attention upon the automobile; for, at least in this country, people travel far more miles by automobile than by all other forms of transportation combined. We obtain a little greater appreciation of the tremendous amount of motor vehicle travel when we note that annual passenger car mileage is about 330 *billion* miles, as compared to 0.5 billion for passenger trains and 0.4 billion for our domestic airlines. From past experience, it appears that this figure of 330 billion is merely a transient point on a curve which as yet shows no sign of leveling off.

AUTOMOBILE TRANSPORTATION

Now for me, or any other man in the automobile business, to predict specifically what the motor car of the future will be like, what changes will be made in each part of the engine, what kind of transmission, rear axles, etc., the future cars will have is obviously an impossibility. I can tell you, however, that the car of the future will be better than the cars you see today, because it is impossible for an industry as great as the automobile industry to stand still. If a committee of experts selected the most advanced model and put it in a glass case to protect it from wear, that car would be just as much out of date ten years from now as a ten-year-old car is today.

One feature of the automotive business not always recognized by the public is its relationship to progress in other fields. The automobile isn't simply the product of a single industry—it is the product of many industries. It moves ahead as the result of new discoveries and developments in the rubber industry, in the steel industry, and in the petroleum industry. It moves ahead as the roads you drive on improve, or as the manner in which the public wants to use this piece of transportation machinery changes from year to year.

Basically, the automobile of the future will be whatever the public that uses it wants it to be, limited only by the ability of the industry's hard-working scientists and manufacturers. Each technological advance permits us to incorporate more new features and ideas into the product; the customer then indicates which of these features will be retained. This has been true since the inception of the automotive age, and will continue so long as the industry is free to retain its present highly competitive nature.

Today's automobiles perform as they do largely because the customer has selected this particular combination of features. Why can't we build cars to give 50 miles per gallon? The answer is that we can. But we couldn't sell them, because today's motorist demands more acceleration, higher speed, and greater riding comfort than can at present be incorporated into such a vehicle. Each manufacturer is striving to provide that combination of performance, fuel economy, handling and riding qualities, and initial cost which will be most attractive to the buyer. All of which comes back to the fact that the manner in which the buyer wants to use his car determines how it will develop in the future.

With these general thoughts in mind, we may wish to take a little closer look at the situation and see what conclusions might be drawn from our previous experience.

Car Performance

In the first place, it seems unlikely that top speeds will be increased to any great extent. Most of us can recall when one of the first questions the prospective buyer put to the salesman was "How fast will she go?" We seldom hear this question now, and the fact that today's cars will go about as fast as most people want them to is confirmed by comparing the present maximum speeds to those of ten years ago. Such a comparison reveals that the 1940 models had substantially the same top speed as those of 1950, the increase being less than 5 miles per hour in most cases.

The trend toward better acceleration and hill climbing ability, which was quite pronounced prior to 1940, has leveled off during the past ten years. Part of this leveling off was due to lack of further development during the war; another factor was an increase in car weight, which served to balance out the improvement in performance which would otherwise have been obtained. The new-car buyer is keenly aware of car performance, and we will probably see some increase in this quality in the cars of the future. However, a few of our present vehicles already have sufficient power to spin the rear wheels on concrete, and it is unlikely that the performance of these cars will be increased to any great extent. Other models with smaller engines will continue their trend toward more power, but even these cars will feature increased fuel economy.

High Compression Engines

As indicated previously, performance and fuel economy are opposing factors, and optimum conditions for one are achieved only at a sacrifice of the other. However, any increase in over-all efficiency may be used to improve either or both of these quantities. Now there are many things which may eventually be perfected so as to give us greater

efficiency, but the most important, and the one most likely to yield the greatest future gains, is the engine. These gains will be obtained by using engines having higher compression ratios.

Engineers have long known that the key to higher efficiency in internal combustion engines is in increasing the compression ratio. In the past, attempts to utilize this important principle in spark ignition engines were largely limited by the quality of the fuel available. As a result, the engineer has been able to increase compression ratios only as rapidly as the petroleum industry could increase the octane rating of their gasoline. Past progress is illustrated by comparing compression ratios of twenty-five years ago to those of today. At that time they were about 4.5 to 1; today the average compression ratio is 7 to 1. This increase was, of course, made possible by the development of high antiknock fuels. Coupled with other engine improvements, it has enabled today's car owner to save one-third the cost of his fuel as compared to the owner of twenty-five years ago. This one-third better fuel economy saves the public over a billion dollars each year.

The production of high antiknock fuels was greatly stimulated by the demands of our air force during the war, and it was apparent that fuel quality would permit a marked increase in the compression ratio of post war cars. However, existing engines were approaching the point beyond which further increases in compression ratio would be limited by engine characteristics rather than by fuel detonation problems. Fortunately, our people were well aware of this situation, and had already set out to do something about it.

As frequently happens, one of the first things we had to do was to disprove what some engineers had accepted as a basic truth—that it would be impossible or at least impractical to build an engine which could operate smoothly under the high loads encountered with high compression ratios. We felt certain, however, that it would be worthwhile to thoroughly investigate the problems and possible benefits of engines having compression ratios up to twice as high as those then in production.

Our first studies were conducted with single cylinder laboratory engines, using triptane, a very fine fuel which we produced for the government in a small scale pilot plant during the war. Triptane has a knock rating far above 100 octane fuel, and permitted us to run our single cylinder engines at compression ratios in the range of 15 to 1.

Out of this single cylinder work came sufficient encouraging data to warrant building a six cylinder high compression engine for testing in a standard production Oldsmobile. Our single cylinder studies had indicated that a good compromise between high compression problems and benefits was obtained at a ratio of about 12.5 to 1, and this ratio was used in designing the new engine. Rather conventional design procedures were followed except that all components were made more rigid

so as to carry the higher loads imposed. In addition, engine displacement was set at a rather low value, so that the developed horsepower would be comparable to that of a standard Oldsmobile engine. This enabled us to present a very practical demonstration of its smoothness and general performance.

To do this we used two identical cars, one the standard production model and the other containing the new engine, and asked various engineers to drive first one car and then the other. Since each engine had about the same horsepower, it was evident that there should be no appreciable difference in over-all performance. The test would, however, reveal any tendency toward roughness, sluggishness, or whatever other flaw the driver might be expecting to find in the new engine. Those who drove the car confirmed our statements that the two engines behaved about the same.

The real progress which the engine represented, and which could not be observed by test driving the car, was its greatly increased fuel economy. A check of the constant speed level road economy of the two cars showed that, under these conditions, the high compression car gave from 35 to 40 per cent better economy in miles per gallon than the standard car. Although these data were important from an engineering standpoint, they gave only part of the story, because automobiles are not driven on level roads at constant speed very much of the time. Approximately two-thirds of the gasoline is consumed in city driving where a large percentage of the operation is transient and requires the entire throttle range of the engine.

In order to determine the economy gains under more typical driving conditions, a number of cross-country trips were made in which both cars were driven together at the same speed through the same traffic. On a large number of such trips under widely varying road conditions the average gain in economy was about 33 per cent, although under some conditions gains approaching 50 per cent were obtained. Several extended trips made entirely in city traffic showed gains of over 40 per cent, which is of major importance in view of the large quantity of fuel burned under these conditions.

The important thing to remember about all this is that these gains were obtained under actual driving conditions, and that high compression engines are completely suitable for mass production. So this thing of greatly increased economy through high compression ratios is not just an impractical experiment in a research laboratory. These very large gains, which become simply enormous when we consider the millions of passenger cars manufactured each year, will be available to the motoring public as soon as the petroleum industry can supply large quantities of fuel with a sufficiently high antiknock value.

How soon will that be? Well, let's say it all depends. In the first place, it depends on the rate at which the octane rating of commercial

gasolines can be increased. Upgrading the fuel is the most obvious way of solving detonation problems, and the public's current interest in and purchase of advanced engines requiring the very best fuels which are available today have served to spark the race among petroleum refiners to develop better fuels.

A second consideration is just how high an octane rating will be required for the satisfactory operation of a production 12 to 1 engine. Fortunately, this fuel-engine relationship has two sides, and the automotive engineer will be able to contribute mechanical octane numbers which are just as effective as the chemical octane numbers produced by the petroleum industry. For example, increasing the compression ratio of a certain engine by one ratio (e.g., from 7 to 1 to 8 to 1) might require that we increase the quality of our fuel by about eight octane numbers. Therefore, if we could take the engine which now operates at 7 to 1 on a given fuel, and redesign it so that it would operate at 8 to 1 on the *same fuel*, we would have built the equivalent of eight chemical octane numbers into the engine. In describing this gain, we say that we have added eight mechanical octane numbers to the engine.

With our previous tests having already demonstrated the vast savings in fuel costs and natural resources which lie just ahead of us, we are working hard and making good headway in locating possible sources of these mechanical octane numbers. So far it appears that the most fertile field is in combustion chamber design, and our prospects along this line look very encouraging.

Although we cannot manufacture our 12 to 1 engines this year or perhaps not even next year, we can build engines capable of utilizing the best fuel available. At the present time there are in production three engines, operating at about 7.5 to 1 which may be readily modified to operate at succeedingly higher ratios until they have reached the 12 to 1 figure. It seems certain that other engines introduced in the future will follow a similar pattern, to facilitate obtaining the maximum possible benefit from the continual technological advances of the petroleum industry.

Automotive Gas Turbines

In the last year or so two turbine-driven vehicles have received considerable publicity, so it might be well to comment on the probable future of automotive gas turbines.

The British Rover passenger car and the Boeing truck installations have both demonstrated that such vehicles can be propelled by gas turbine. This point has never been questioned. The question, of course, is whether such machines can be made competitive with our present automobiles and commercial vehicles.

Among the advantages claimed for the gas turbine are high starting acceleration, the ability to use a wide variety of fuels, simplified ignition

and lubrication, and less vibration due to the absence of power impulses. These advantages do exist, but in obtaining them we inherit several knotty problems.

For example, to obtain the high rate of acceleration reported, the driver of the Rover car was required to hold on the brakes, run the gas generator up to near rated speed (40,000 rpm.) and then release the brakes, at which time the stop watch was started. The acceleration from idle (7000 rpm. on the gas generator) on the other hand was reported as being rather slow. Moreover, neither the Rover nor the Boeing engine has a power unloader or neutral position. This is equivalent to having an automatic transmission locked in the drive position at all times. The addition of an unloader or by-pass between the gas generator turbine and the power turbine is not impossible, but will certainly result in a more complicated control system.

One of the most serious limitations is the fuel consumption of these units. Although they will operate on kerosene or diesel oil, present consumption is more than twice that of a piston engine of equivalent power. It is expected that this will be improved through the use of regenerators, which will, however, complicate the space problem. The basic turbine is generally a small, compact unit, but the installed turbine with its bulky ducting is not a space saver.

Further handicapping the turbine for vehicle use is its high idle fuel consumption, since it appears that the automotive gas turbine may be expected to use one-fifth as much fuel at idle as it would at full throttle. There does not appear to be any ready solution for this problem.

Another difficulty is the lack of braking power provided by the turbine. Lifting the accelerator pedal gives a free-wheeling sensation at high speed, indicating that present-day brakes would have to be markedly improved or some auxiliary braking system developed. Similarly, intake and exhaust noise would have to be reduced without using overly large silencers. These problems are not insurmountable, but serve to emphasize the many related or side problems created by the turbine characteristics.

Work in the turbine field is progressing rapidly, and although it seems unlikely that turbines will be used to drive cars and trucks in the foreseeable future, no one can say it is impossible. Should future developments make the turbine competitive, it will almost certainly first appear in trucks and busses, since functional design can be carried out to a greater degree in these installations.

Perhaps we may best sum up the turbine's future in road vehicles by suggesting that it may one day supplement diesel and gasoline engines but is not likely to replace them. In each case the turbine must prove that it is not only equal to but is better than the engines which are now providing such dependable service.

Other "New" Engines

Today, as always, a few people are experimenting with other engines markedly different from those now in use. Some of these designs incorporate relatively new ideas, while others attempt to make practical designs previously discarded as unworkable. However, we do not expect the present poppet valve reciprocating engine to be replaced for many years to come. Its compression ratio will definitely be increased; no doubt further refinements will appear in carburetors, ignition systems, head design, manifolding, etc. But the basic operation of the automotive engines of the next fifteen to twenty years will probably be the same as those of today.

Automatic Transmissions

Certainly the most revolutionary change in the industry in many years has been the recent widespread adoption of completely automatic transmissions. The first of these transmissions was introduced in 1940, but, largely because of the war and the attendant reconversion problems, there were still relatively few on the road at the end of 1947. About that time other manufacturers began to offer this driving convenience, and at present automatic transmissions are being produced at the rate of well over one million per year. This figure is still rapidly increasing, and it is likely that within five years a large majority of all cars sold will be so equipped.

RAILROAD TRANSPORTATION

Most of us have relatively infrequent contact with the railroads, so it is only natural that we are more aware of progress and changes in automobiles than of advances in rail transportation. However, almost any improvement in railway equipment is certain to benefit all of us, irrespective of the number of trips we make, for how many things which we use each day have not at one time or another been transported over the rails which serve to integrate the various segments of our complex economic system?

Today the railroad industry is in the intermediate stages of a truly remarkable technical revolution—the replacement of the steam locomotive by the diesel-electric. I say "remarkable" with reason, for in less than fifteen years after its introduction, the high-speed diesel obsoleted an engine which had been used and perfected for more than a century. Part of the rather spectacular story of the diesel locomotive is told by the figures in the following table. These statistics appeared in the May, 1949, issue of *Diesel Power and Diesel Transportation*, and show the number of each type locomotive in service, by years, for Class I railroads (Class I roads are those with an annual gross revenue of over $1,000,000).

Steam and Diesel Locomotives in Service—Class I Railroads.

Year	Steam	Diesel
1929	56,936	22
1939	41,117	510
1943	39,725	2125
1947	35,108	5772
1949	32,613	7201

It should be pointed out that the 22 diesels in service in 1929 were old style cumbersome engines, saddled with the same high weight-to-horsepower ratio which had always severely limited applications of the inherently efficient diesel. We had begun to work on this weight problem about 1928, and by 1934 had developed an engine which found quick application in the first light weight streamlined diesel locomotive, the Burlington *Pioneer Zephyr*, whose maiden run in April of that year was to usher in the development of a completely new industry.

Little more than a month after its inaugural run, the *Pioneer Zephyr* gave a spectacular demonstration which foretold the shortened schedules soon to appear on the main line routes. This was the now famous Dawn-to-Dusk run, in which the *Zephyr* clipped nearly 13 hours from the fastest scheduled steam time between Denver and Chicago. Since that time, the fast schedules and punctuality of diesel passenger service have become familar to all of us, and these shortened schedules in themselves might well have been sufficient reason for the adoption of this new power source.

Not so widely appreciated, but even more important, is the improved operating economy of the diesel. The over-all thermal efficiency of this engine is in the order of 32–38 per cent, whereas the simple steam engine has an efficiency of about 6 per cent. Although diesel fuel is more expensive on a BTU-per-dollar basis, the marked difference in engine efficiencies permits the diesel to operate with a fuel cost of a little more than half that of the steam engine. Further savings result from reduced maintenance costs, modern diesels requiring far less attention than do their steam counterparts.

Consequently, the immediate future of railroad transportation may be summed up in two words—further dieselization. Today there are on order no steam passenger locomotives and only a very few steam freights and switchers, these orders having been placed largely for reasons other than the performance and operating cost of the engines themselves. The greatly reduced operating cost of the diesel is encouraging the railroads to accelerate the replacement of their present steam engines to the greatest extent possible, and already a few roads have become completely dieselized. It is at this point that still more savings are effected, with the elimination of water columns, pump stations, coaling stations, and other costly supporting services. For

example, one road, now completely dieselized, had been spending $70,000 per year in fire claims and in maintaining fire patrols to combat grass fires caused by steam locomotives. Moreover, the higher availability of the diesel engine permits a fully dieselized road to operate with fewer locomotives. The greater availability of the diesel is apparent from the preceding table, which shows that 7000 diesel locomotives have replaced 24,000 steam engines during the last twenty years, in spite of a 50 per cent increase in both passenger miles and ton-miles of freight during this same period. Still other economy factors are a reduction in locomotive water required, and a saving in track maintenance expense, since diesels are known to cause less damage to road beds and trackage than do the reciprocating steam engines.

The Diesel Rail Car

It is fortunate for the railroads that the diesel was freed of its weight shackles as early as it was, for it has been the speed, cleanliness, and comfort of the diesel streamliners which have enabled the railroads to compete with other forms of modern transportation. Although the main line passenger runs are, in general, profitable operations, the industry has for many years reported a large number of local or short line runs in red ink. This deficit has been largely the result of high operating expenses and few passengers. But a new application of the diesel engine—the diesel rail car—introduced in May, 1950, gives promise of switching these annual losses to the profit side of the ledger.

Of course, rail cars aren't new at all, having been used even before World War I, but heretofore no one had built one using a modern streamlined car and modern diesel engines. The two new air-conditioned units now serving New England commuters are a far cry from the old distillate-burning rail cars, and a refreshing improvement over the dingy, rattly coaches serving many commuters today.

The technical features of this completely self-contained one-car train are of interest in that new techniques are employed in order to insure satisfactory performance. Subway-type electric controls regulate twin 275 horsepower diesels, whose power is transmitted to the wheels through specially designed hydraulic torque convertor transmissions. The cars may be operated singly or in multiple. Four types of interior arrangement are available to satisfy various passenger-baggage requirements, thus giving additional service flexibility. Top speed is 83 mph., with most efficient operation obtained at about 70 mph.

How successful the diesel rail car will be is still a debatable question, but its qualities seem to fit the type of service for which it was designed very well. The previously discussed operating advantages of diesel locomotives likewise hold true for the rail cars, and the relaxation permitted by the pleasant, comfortable surroundings should prove most attractive to the traffic-conscious suburbanite, as well as to other short-distance travellers.

Railway Gas Turbines

As in the case of the automotive industry, there has been considerable speculation as to the applicability of the gas turbine to the railways. The simplicity of the turbine plant (which, if perfected, could mean long periods between overhauls), coupled with its ability to use very low grades of fuel, have been strong selling points for the expenditure of millions of dollars for further turbine research and development work. Already a 4500 horsepower gas turbine-electric locomotive has been built and subjected to hundreds of hours of laboratory tests, and is now providing operational data by serving as a freight locomotive on one of our western roads.

Many of the limitations which handicap the turbine for automotive service are also encountered in railway applications. For instance, the inherently low thermal efficiency of the turbine is an ever-present stumbling block, the greatest hope for improvement in this respect resting in the hands of the metallurgist. No doubt improvement in design can help somewhat, but the development of better alloys—thus permitting operation at higher temperature—seems to be the key to higher efficiencies.

Another condition common to both automotive and railway power plant operation (and one that is a headache to the turbine designer) is the large amount of part-load operation involved in each case. In comparing the load *vs.* efficiency curves of the two engines, we find that the diesel's efficiency is fairly constant over a large range of load, whereas that of the gas turbine tends to peak up rather sharply at one particular load. This, of course, comes back to what we have previously mentioned in connection with automotive usage of the turbine; that is, the turbine's fuel consumption at light load is a large part of its full-load requirement. The seriousness of this drawback will naturally vary with each particular railroad application, obviously being greatest in switching and mountainous operation.

In looking into the future of the gas turbine, we should always keep in mind the need to correlate power plant characteristics with those required by the job. The characteristics of the ideal railroad engine are approximated to a much greater degree by the diesel engine than by the gas turbine. Consequently, if the turbine is to come into widespread use, it must become so attractive from a maintenance and low-cost fuel standpoint that the railroads will be willing to accept the natural limitations of the turbine proper. In this connection, I might point out that the railroad diesel enjoys its present dominant position because it represents a *very great* improvement over the steam engine. Had this improvement been only moderate, it is highly unlikely that the railroads would have abandoned their then-satisfactory steam locomotives and have made the extensive maintenance and operational

changes necessitated by the adoption of a completely new locomotive. Today, it is difficult to foresee the gas turbine offering a similarly great improvement over the diesel engine, and it is evident that the railroads are not going to be faced with demands for an extra fireman on gas turbine locomotives for a long, long time.

SUMMARY

Nearly all prognostigators, from the fellow who buys a $2 ticket on *Blue Boy* to the financial policy-makers of government and business, base their final conclusions upon past experience. Properly tempered (and herein lies the success or failure of the prophet), this is a completely logical procedure, and is especially applicable to engineering trends, for most of our technical progress has been achieved through a process of evolution.

Thus, one of the best ways to gain an insight as to the direction in which we're going is to note our present position and to review how we reached it. In the preceding discussion, I have tried to cover a few specific phases of our transportation future in just this fashion, in order to emphasize that we can expect tomorrow further applications and extensions of the things we are working with today.

COSMIC RAYS

BY

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INTRODUCTION

In a paper of such length as is appropriate for this occasion, it is impossible to deal exhaustively with all branches of the subject. I wish, therefore, to confine myself to an over-all survey of most of the features but shall concentrate in detail upon that aspect which has to do with the origin of the primary radiation itself.[1]

THE GENERAL NATURE OF THE COSMIC RADIATION

Within recent years, we have come to believe that, as a first approximation at any rate, the primary rays coming to us from outside our atmosphere are protons. The protons disintegrate in the higher regions of the atmosphere, giving rise to lighter particles called mesotrons which, in turn, disintegrate into electrons and neutral particles called neutrinos. It is generally believed that few, if any, electrons participate in the incoming primary radiation itself.

The electrons produced by the disintegration of the mesotrons give rise to gamma-rays on impact with the atmosphere, which in turn materialize into other electrons, positive and negative, and these electrons repeat the story giving rise to successive generations of progeny, until the energy available from the original electron is spread out over so many offspring that the amount falling to each is too small to provide for continuation of the multiplicative process, at which stage further loss of energy by the electrons is confined to loss by ionization of the atmosphere. The various components, gamma-rays, positive and negative electrons, resulting from the multiplicative process, enhanced to some extent by other electrons shot out of atoms through impact with mesotrons, constitute what, in years past, was vaguely referred to as the soft component of the cosmic radiation.

The mesotrons, in virtue of the fact that their mass is large compared with the electronic mass, do not multiply by the process characteristic of electrons and lose their energy only by ionization, so that, with such energies as they are known to possess, they are capable of passing right through the atmosphere and to great depths of the earth below it.

The disintegration of the protons into mesotrons is a phenomenon

[1] Where the discussion becomes involved, particularly in the matter of mathematical details, such details will be relegated to an appendix to this paper with appropriate references.

confined practically to the top ten per cent of the atmosphere and but few protons succeed in penetrating very much lower.

Extension of the Simple Picture of the Primary Radiation and of Mesotron Formation

The foregoing picture is now known to be only approximate in the sense that particles heavier than protons also participate in the primary radiation.[3] About 25 or 30 per cent of the incoming particles are charged helium atoms, or alpha particles. About 1 per cent are particles of atomic weight comparable with carbon, nitrogen, or oxygen, and about one-third of 1 per cent are composed of nuclei with atomic number greater than 10. However, the importance of these heavier components of the cosmic radiation is greater than may appear from the smallness of these percentages, for an alpha particle, for example, contains four times as many nucleons as does a proton, which contains only one, and since the richness of generation of mesotrons by a particle is proportional to the number of protons in it, the alpha particles in the aggregate give rise to half as many mesotrons as the protons produce. Similar remarks apply in more drastic form to the heavier nuclei. Taking into account all of the heavier particles, fully 50 per cent of the nucleons come from primaries which are heavier than protons. Moreover, these heavier primaries are the source of neutrons, since neutrons are contained in their nuclei, and neutrons play an important part in the upper atmosphere in causing atomic disintegration.

The story of the mesotron is also rather more complex than is implied in the simple picture first given. The ordinary mesotron observed in cosmic radiation—the μ-mesotron, as it is called—has a mass about one tenth that of a proton and a life expectancy, when moving slowly, of the order of two millionths of a second. It is, however, not always, and perhaps never the immediate offspring of the proton or other nucleon. The immediate offspring, at any rate in many cases in nuclear physics, is a mesotron, 50 per cent more massive, and known as a π-mesotron when it is positively charged and as a σ-mesotron when it is negatively charged. The π- and σ-mesotrons in addition to having masses about 50 per cent greater than that of the μ-mesotron have a very much smaller life expectancy. The π-mesotron at death is believed to disintegrate into a μ-mesotron—the ordinary mesotron observed in cosmic rays—of 4.1 million electron volts energy, together with a neutral particle—a neutrino—of mass comparable with that of the electron and traveling with 31 million electron volts energy in a direction opposite to that of the μ-mesotron. The μ-mesotron, on disintegration, decays into an electron, with an energy which may be anything from zero up to

[3] M. A. POMERANTZ AND F. L. HEREFORD, *Phys. Rev.*, Vol. 76, p. 997 (1949). H. L. BRADT AND B. PETERS, *Phys. Rev.*, Vol. 77, p. 55 (1950): This article also contains reference to earlier experimental work. On the basis of Zenith angle measurements, the presence of Helium atoms was predicted by the present writer in 1943: JOUR. FRANKLIN INSTITUTE, Vol. 236, p. 1 (1943).

55 million electron volts, and into two neutrinos traveling in the opposite direction with energies adjusted to provide for conservation of energy and momentum.

The σ-mesotron appears to behave in a manner more complicated than that characterizing the π-mesotron, and we shall not pursue the history of this matter here.

Nuclear Disintegrations in the Atmosphere

During the last few years much attention has been given to phenomena which show themselves, particularly at high altitudes, in the form of starlike structures in photographic plates and in cloud chambers. These stars represent nuclear disintegrations resulting from the impact of nucleons or mesotrons with the atoms of the air. They are characterized by prongs which radiate from the center of impact and which vary in number from one or two up to a great many. It is frequently possible to identify the particles which have produced the various prongs by their range and by the extent of their photographic action or ionization, and it is also frequently possible to identify the original nucleon which has been responsible for the disintegration. In such identification, much use is made of the principles of conservation of energy and momentum which must be satisfied and in the application of which the angles between the prongs play an important role. By studies of events of this kind there has recently arisen evidence for the existence of a new charged particle with a mass comparable with 700 electron units,[3] a particle, moreover, which decays into two other particles, one penetrating and charged and the other neutral. There is also evidence for the existence of a neutral particle of mass comparable with 800 electron units,[4] with a life expectancy of about 3×10^{-10} second and which decays into two charged particles.

Measurements of slow neutrons in the atmosphere[5] yield values which show a maximum of intensity at a pressure of about 8.5 cm. Hg, the intensity falling to about one-fourth of its maximum value at a pressure of 1 cm. Hg.

Extensive Showers

One of the most dramatic manifestations of cosmic ray phenomena is to be found in the existence of showers of particles which arrive simultaneously over areas of very wide extent, areas of 300 meters or more radius.[6] The inference is that such a shower, while complicated

[3] H. H. FOSTER, *Phys. Rev.*, Vol. 77, p. 733 (1950).

[4] C. D. ROCHESTER AND C. C. BUTLER, *Nature*, Vol. 160, p. 855 (1947). A. J. SERIFF, R. B. LEIGHTON, C. HSIAO, E. W. COWAN AND C. A. ANDERSON, *Phys. Rev.*, Vol. 78, p. 290 (1950).

[5] LUKE C. L. YUAN, *Phys. Rev.*, Vol. 77, p. 728 (1950).

[6] Phenomena of this kind, with a simultaneity of occurrence of particles at distances of 1.5 meters, were observed by the present writer in collaboration with W. E. Ramsey (W. F. G. SWANN, JOUR. FRANKLIN INSTITUTE, Vol. 226, pp. 757 and 598 (1938)). At about the same

in its structure in that it may contain particles of various kinds, electrons, mesotrons, etc., is nevertheless to be regarded as having its origin in a single parent. Estimates of the total energy involved in such showers lead to the conclusion that the parents must be assigned energies as high as 10^{16} or 10^{17} e.v.

THE LATITUDE EFFECT AND THE SUN'S MAGNETIC FIELD

The discovery of the latitude effect [7] first crystallized itself into a simple picture in which it was believed that, starting at the magnetic equator at sea level, the cosmic-ray intensity increased with increase of magnetic latitude until, at a certain latitude, it suddenly ceased to increase further, and the explanation of this phenomenon was sought at that time in terms of a single primary radiation which traversed the atmosphere. On this view, the earth's magnetic field prevents the entry of rays below a certain momentum at the equator, and as the latitude increases, the lower limit for entry becomes less and less, until at the magnetic pole it becomes zero. On this explanation, it is clear that the measured cosmic-ray intensity at sea level should increase with increasing latitude. However, it is obvious that it should not increase beyond a certain latitude, namely the latitude at which the lower limit of momentum for entry is such that rays with that momentum could only just penetrate the atmosphere. Beyond this point, and for higher latitudes, the additional rays permitted to enter are not able to penetrate to sea level, so that beyond this latitude no increase of intensity is to be expected. The point in the curve where a further increase of intensity ceased to take place was known as the cut-off point.

It was expected that the cut-off point would occur at higher latitudes for higher altitudes. However, certain evidence came forth to indicate that the cut-off point was independent of altitude.[8] It may be remarked at this stage that if one takes the kind of spectral distribution which had been assumed for the incoming primary rays, one calculates that there is not very much change in the latitude of the cut-off point for a considerable change of altitude, so that it is not safe to draw too heavily upon experiments which tend to show that there is no change at all in the latitude of the cut-off point with altitude. However this

time, P. Auger, R. Maze and T. Grivet-Meyer (*C. R. Acad. Sci.*, Paris, Vol. 206, p. 1721 (1938)), P. Auger and R. Maze (*C. R. Acad. Sci.*, Paris, Vol. 207, p. 228 (1938)) and P. Auger, R. Maze, P. Ehrenfest, Jr., and A. Freon (*J. Phys. Radium*, Vol. 10, p. 39 (1939)) observed similar phenomena. The investigations became extended by P. Auger, R. Maze, and Robley (*C. R. Acad. Sci.*, Paris, Vol. 208, p. 1641 (1939)) in subsequent work to the observations of simultaneous showers of particles at distances up to 300 m. Since that time a large amount of work has been done on the subject.

[7] The latitude effect was first observed at sea level by J. CLAY, *Proc. K. Akad. Amst.*, Vol. 30, p. 1115 (1927); Vol. 31, p. 1091 (1928); Vol. 33, p. 711 (1930); Vol. 35, p. 1282 (1932)). It was verified by A. H. Compton and his collaborators in a world survey, and since that time, many observers have investigated the matter.

[8] M. COSYNS, *Nature*, Vol. 137, p. 616 (1936).

may be, it came to be surmized that perhaps something other than the earth's magnetic field took precedence of that field in determining the cut-off, and appeal was made to the magnetic field of the sun which, as a result of observations made by Hale some 40 years ago, was generally believed to have a magnetic moment of amount sufficient to give a magnetic field of about 50 gauss at its pole.

If we imagine a sphere with the sun at its center and of radius equal to the distance of the earth from the sun, then the theory of the magnetic cut-off due to the sun's magnetic field on this sphere is of exactly the same nature as the theory of the cut-off with varying latitudes as a result of the earth's magnetic field. However, in the case of the sun, we are concerned only with the cut-off at the aforesaid distance *in its equatorial plane*. In view of the fact that the cut-off due to the sun at this distance is determined by deviations of the particles produced by a very weak field through large distances of space, most of the contribution to the deviating action is performed outside the earth's magnetic field and we can, to all intents and purposes, neglect that field in finding the cut-off due to the sun. It thus resulted from the calculations that singly charged particles with momentum less than 3 Bev/c could not reach the equatorial plane of the sun at all at a distance equal to that of the earth from the sun. Particles of higher energy could reach the earth, and these particles would be acted upon by the earth's magnetic field and would have thereby a latitude effect determined for them by that field but the increase of intensity with latitude would be expected to cease at the latitude corresponding to a momentum of 3 Bev/c, so that at the earth's surface further increase of latitude would result in no more rays coming in, because there would be no more rays of lower momentum to come in. At higher altitudes the story would be the same.

Since the latitude effect is not very large at sea level but is much larger at higher altitudes, it was natural to perform experiments over varying latitudes at such altitudes to verify with greater certainty whether there was or was not an increase of intensity beyond the latitude (about 50° magnetic latitude) at which the sun's supposed magnetic field would determine a cut-off. With this idea in mind, experiments were performed [9] some 12 years ago and claimed to show that there was indeed no increase of intensity with increase of geomagnetic latitude from 49° to 88° at higher altitudes. However, these experiments were few in number and depended for their interpretation upon standardization involving different pieces of apparatus in a manner which cast considerable doubt upon the interpretation which was actually made. For these reasons, M. A. Pomerantz [10] made an exhaustive series of measurements at high altitudes a year and a half ago and found an increase of

[9] H. CARMICHAEL AND E. G. DYMOND, *Nature*, Vol. 141, p. 910 (1939); *Proc. Roy. Soc.*, Vol. 171, p. 321 (1939).

[10] M. A. POMERANTZ, *Phys. Rev.*, Vol. 77, p. 830 (1950).

intensity at altitudes comparable with 20 miles between latitudes 52° and 69°, the increase of intensity amounting to 46 per cent. Viewed from another angle, it was possible, by absorption measurements in lead, to determine the character of the additional rays which were observed at the higher latitudes and ascertain in fact their momentum. Results, which have been confirmed by experiments performed last summer, serve to show that at the higher latitudes rays with momentum as low as several tenths Bev/c were being measured in appreciable amount and such rays could never have reached the earth at all if the sun's magnetic field had had a value anything like 50 gauss at its pole. In fact the limiting value possible for the magnetic field at the sun's pole and consistent with Pomerantz' experiments, would be no more than 2 gauss.

In spite of the above conclusions, it must be admitted that there is another interpretation of the data which permits the sun to retain its magnetic field and yet be consistent with the observations. This interpretation involves considerations which are even more interesting than those pertaining directly to the sun's magnetic field itself. If the cosmic rays actually come from the sun, then, while the magnetic field of the sun presents problems concerning their ability to get away from that body, once they are well away from it the deviation in their journey to the earth would not necessarily be of a drastic nature such as to prevent their reaching the earth; for, as already stated, the sun's action on particles coming from an infinite distance is one which operates over very large distances in space. The bending of the paths of the rays in coming towards the earth's orbit is very slow but persists for great distances. Rays coming from the sun itself have but relatively small distances to travel in order to reach the earth. Thus, the experiments of Pomerantz may be interpreted in each of the three following ways:

(*a*) If we assume that the cosmic rays come from great distances, the experiments demand that the sun shall have a magnetic field far smaller than that formerly supposed to exist.

(*b*) If, for other reasons, we believe that the sun has a magnetic field comparable with its formerly accepted value, we are driven to suppose that the cosmic rays come from an origin relatively near to the earth, and the only obvious origin is the sun or the space in its immediate vicinity.

(*c*) If the rays do come from the sun or from its vicinity, the experiments of Pomerantz have nothing to say regarding the general magnetic field of the sun.

Perhaps an additional comment on this matter should be added. Orbits in the sun's field which could well have been reached by particles coming direct from very great distances may, nevertheless, be fed by particles from infinity by a process in which the said particles are de-

flected into such orbits by the earth's magnetic field. They may then be able to circulate in such orbits for a long time. They become in fact trapped in such orbits until finally they strike the earth or some other celestial body, or become destroyed by collision with atomic nuclei in space. Such a possibility as this has been suggested by Alfvén.[11]

Now the question of the cosmic rays originating in the sun or in its vicinity is one which has been mooted from time to time and much attention has been given to the matter within the last two or three years. These considerations will be discussed later. It is perhaps sufficient to remark at this stage that if we seek the origin of the cosmic rays as a result of what we may call the normal operations occurring in stars, that is, operations which may be supposed to occur in all of them, then, although all the stars might contribute to the cosmic radiation which we observe, we might expect that, in comparison with our sun, they would only contribute in the proportion of starlight to sunlight. However, in spite of this rather debatable argument, evidence, as we shall see, has been offered in support of the view that the stars are major contributors to the cosmic radiation.

Quite apart from the foregoing considerations, the astronomers, who were originally responsible for the claim that the sun possesses a general magnetic field of such a magnitude as to correspond to 25 or 50 gauss at the pole, have found reason to doubt this conclusion. Indeed Thiessen [12] who originally was one of the strongest supporters of the earlier value for the sun's field, has concluded that a strict analysis of the original data, while not denying the existence of the larger field, does not support such a field with any certainty. His recent observations, moreover, made and analyzed with great care and accuracy, using improved methods, have led to a solar value comparable only with about 1 gauss and in the opposite direction to that formerly found. In this connection it is to be remarked that observations of the field at one epoch are not necessarily a guarantee of its value at another. This reservation, which might under ordinary circumstances be regarded as trivial, assumed a greater cogency from the fact that some stars are known with certainty to possess quite large magnetic fields and, according to Babcock [13] the star HD 125248 has been found to possess a magnetic field of 6000 gauss at its pole, a field, moreover, which reverses itself to a comparable value in a period of about 10 days.

THE ORIGIN OF THE PRIMARY COSMIC RADIATION

For many years ideas concerning the primary cosmic radiation centered on the belief that this radiation was to be found with practically equal intensity over the whole of galatic and intergalatic space.

[11] H. ALFVÉN, *Phys. Rev.*, Vol. 72, p. 88 (1947).
[12] G. THIESSEN, *Zeits. f. Astrophys.*, Vol. 26, p. 16 (1949); *Observatory*, Vol. 69, p. 228 (1949).
[13] *Phys. Rev.*, Vol. 74, p. 489 (1948).

However, such an idea is attended with considerable difficulty on the basis of energy considerations. Thus Richtmyer and Teller [14] have pointed out that on such a view the total energy carried by all cosmic ray particles is much more than all the energy ever emitted by stars and the additional amount which the heavenly bodies possess in the form of kinetic energy. This fact raises difficulties as to how the supply of cosmic ray particles could be maintained, particularly in view of the fact that it would be necessary to allow for a continual loss as the result of the collisions of the rays with atoms throughout the whole of space.

As a result of such considerations interest during the last few years has centered upon processes in which the cosmic rays are confined more or less to the galaxies as a result of the confining action of magnetic fields, a matter which will be referred to again later.

We are confronted with the problem of accounting for energies comparable with 10^{10} electron volts and even higher, energies which may range as high as 10^{17} electron volts. There are three general categories which present themselves for consideration:

1. The particles may receive energy by relatively small forces acting over great distances.
2. They may receive energy in single acts associated with enormous forces.
3. The particles, with their energies, may have to be considered in the category of things born with the universe and depending for their origin and properties upon the circumstances associated with that event.

Category (3) is such that it cannot very well be affirmed or denied. In this category we find the suggestion of the Abbé Lemaitre to the effect that the cosmic rays find their origin at the time of the supposed origin of the universe when conditions may have been so drastically different from what they are now that our ignorance of them provides us with sufficient latitude to assume almost anything which might form a basis for the origin of the high energies. Category (2) is deemed unlikely because we now know that the cosmic radiation contains particles much heavier than protons. A process which gave them their energy in a single act would be expected to disintegrate them. The first category, therefore, presents the natural field for explanation in terms of our present knowledge. This category may be divided into two classes, a class in which the energies are acquired little by little by processes which are primarily mechanical, while in the second class the forces are primarily electrical.

Mechanical Methods of Accelerating Particles

Of course, mechanical forces are usually, in the last analysis, electro-

[14] R. D. RICHTMYER AND E. TELLER, *Phys. Rev.*, Vol. 75, p. 1729 (1949). Also, E. TELLER, Paper No. 37, Echo Lake Cosmic-ray Symposium, June, 1949.

magnetic, but it is nevertheless convenient to distinguish between processes which are very clearly the result of electromagnetic forces used in their elementary aspects and those in which any electromagnetic feature is involved in more subtle form.

Thus, in what I have called the mechanical realm, we have such activities as are represented by the pressure of light. An example of such a process has been cited by L. Spitzer, Jr., who considers the problem of the acceleration of small particles under the influence of the radiation pressure from the supernovae.[15] He comes to the conclusion that such particles can under these conditions receive from 0.01 Bev to 1.0 Bev per nucleon of the particle, with the acceleration occurring in from a few weeks down to a few hours.

By supposing that the particles are held within the galaxy by an extensive magnetic field which is postulated for the galaxy, it is supposed that the particles, through collision with atomic nuclei in the galaxy break up ultimately into nucleons, which themselves are lost finally by close collisions with atomic nuclei or by striking large celestial bodies like the earth. An equilibrium condition is set up in which the number of high energy nucleons contributed to the galaxy per unit time is equal to the number lost by the aforesaid processes. By this process a cosmic ray intensity between one per cent of the measured intensity and one hundredth of one per cent is predicted, depending upon assumptions as to the frequency of nuclear collisions in the galaxy.

Fermi's Theory. A more subtle variety of mechanism is one suggested by Fermi.[16] Perhaps the easiest way to think of this theory is to picture a room containing gas molecules and a lot of hard steel spheres flying about and rebounding from one another and from the walls of the room. It will be convenient to eliminate gravity temporarily during our meditations. Now, of course, in the last analysis the spheres will lose their energies to the gas molecules and will finally come to a state of thermodynamical equilibrium in which the average energy of the centers of gravity of the spheres will be the same as that of a gas molecule. If the spheres are of sizeable dimensions, let us say 10 cm. in radius, their average root mean square velocity will then be very small compared with that of the molecules, although their average energy will be the same as that of the molecules. If, however, the spheres are perfectly elastic and if the walls of the room are perfectly elastic, and if the spheres have considerable velocities initially, it will be a very long time before they get to the final state of equilibrium with the kinetic energy of gas molecules envisaged above. On their journey towards that equilibrium, they will seek another quasi-stationary equilibrium in which they have a velocity distribution among themselves which is like that of the gas molecules in following Maxwell's law, for example, but in

[15] L. SPITZER, JR., Paper No. 38, Echo Lake Cosmic-ray Symposium, June, 1949.
[16] E. FERMI, *Phys. Rev.*, Vol. 75, p. 1169 (1949).

which the average kinetic energy of the spheres is enormous compared with that of one of the molecules and is, in fact, approximately equal to the total original energy of the spheres divided by their number. In other words, the spheres have a kind of macroscopic temperature of enormous amount which diminishes only very very slowly to the final temperature representative of the true equilibrium.

The quasi equilibrium of the spheres is not an accidental phenomenon but is an inevitable consequence of the laws of dynamics as applied to the collisions between them.

Suppose now that we imagine the molecules to be reduced in number so that the chances of molecules colliding with one another are very much less than their chances of colliding with the spheres. We may envisage a possibility in which these molecules will become ambitious and seek, through their collision, to accommodate themselves to the kinetic energy of the spheres and in this process acquire velocities much greater than the velocities of the spheres themselves. This ambition, although at first sight fantastic, is not indeed illogical under the specialized conditions which we have assumed and indeed the dynamical laws of the collisions substantiate it.

In the Fermi mechanism our steel spheres are replaced by bounded magnetic fields associated with moving masses of gas in the galaxies. A magnetic field of this kind is a very good representative of a hard elastic body, because an electric particle entering it is turned back to the region from which it came without any loss of energy as measured in the frame of reference in which the magnetic field is at rest.

However, there are certain difficulties in the Fermi mechanism, the chief of which are the following: When an ion has acquired appreciable velocity it starts to lose energy by ionizing other atoms in its path; and while the density of matter in space is very small, the rate of loss of energy by this process competes so seriously with the rate of gain by the Fermi mechanism as to dominate the situation for low energy where the ionization probability is greater. Only when the particle has attained an energy comparable with the lower range of cosmic ray energies where the ionization loss is small is the Fermi mechanism capable of taking hold to increase further the energy of the particle. Moreover, in this matter heavy particles are at a disadvantage with respect to light particles. Thus, the Fermi mechanism requires a kind of injector process to get it started. Another action operating to prevent increase of energy is the radiation which occurs when the particle, on collision with a magnetic field, changes its direction of motion. This process is of significance, however, only for light particles like electrons, but for them is sufficient to prevent the Fermi mechanism from becoming operative at all.

Then, since the average energy gained by the mechanism is only about 10 electron volts per collision and since one can anticipate only

about one collision per year, about 60 million years would be necessary for a particle to acquire cosmic ray energy. During this period, it has an opportunity for making collisions with the nucleus of a particle in the surrounding space and such a collision, as we know from the evidence presented by protons entering our atmosphere, results in destruction of the particle and its conversion into mesotrons. It appears that as our knowledge of the orders of magnitude of the quantities concerned becomes more complete, the strength of the evidence against the possibility of the Fermi mechanism increases also, one of the most potent difficulties arising from the time necessary for the particle to acquire cosmic ray energies and the chance of its destruction during that time.

As regards injector mechanisms necessary for starting the Fermi mechanism, several such have been suggested. One due to L. Spitzer, Jr., has already been cited, and envisages the supernovae as injectors. It is supposed that during the stellar explosion corresponding to the nova, the pressure of the intense light radiation can accelerate particles to energies corresponding to those at which the Fermi process may take hold.

One of the most curious suggestions as to the origin of cosmic ray energies has been made by J. M. Barnothy and M. Forro.[17] The proposal which, in its abstract form, concerns itself with the recognition of two time scales applicable to different kinds of phenomena in the universe, can, in less sophisticated language, be interpreted as a supposition that the wave length of light lengthens with increase of time but that Planck's constant, h, increases with time in such fashion that $h\nu$ for a photon coming from a great distance increases during its journey over that distance and to such an extent that while it may have had the characteristics of ordinary light at the commencement of its journey, it appears to us many eons later as a photon with cosmic ray energy.

Electromagnetic Methods

Turning now to electromagnetic methods of accelerating particles, we have two general classes, those where the fields arise strictly from a potential—from a distribution of statical charges—and those where they arise from electromagnetic induction.

Cases where the Field is Strictly Derivable from a Potential. In cases where the field is wholly derivable from a potential, we face the necessity of assuming that between different parts of the universe there shall be differences of potential corresponding to the values of the energies which it is desired to account for in the cosmic rays. Now space contains about one atom per cc.; and through the existence of radiation in space, these atoms are probably all ionized. One ion per cc. is not much, but it constitutes a sizeable effective conductivity for space.[18] A potential

[17] Echo Lake Cosmic-ray Symposium, June 23 to 28, 1949.

[18] See Appendix, Note 1, for remarks on the conductivity of space.

difference initially established would become annulled in a relatively short time by this conductivity. An illustration of such a situation is one where we suppose that a star, charged initially to a very high potential in relation to its fellows, provides the field necessary for acceleration of the cosmic rays. However, if there is a constant means of replenishing the potential difference, annihilation of the field will not result. The matter is analogous in its simplest aspects to the case of a galvanic battery where the fields are derivable from a potential which would disappear almost immediately were it not for the galvanic action operating at the electrodes. Another illustration is provided by a mass of conducting gas moving through a conducting medium with a magnetic field perpendicular to the line of motion.

Motion of a Conducting Mass of Gas through a Magnetic Field. For convenience, we may think of the mass of gas in the form of a slab with its flat ends parallel to the magnetic field and in motion perpendicular to the field and parallel to the flat ends. The motion of the conductor in the magnetic field sets up a force perpendicular to the plane of the slab and this force moves charged particles in such a manner as to bring about a counteracting electric field which, in the case where the external medium is non-conducting, balances completely the force due to the magnetic field in the frame of reference in which the slab is moving. In other words, in this case the slab becomes like a charged condenser. If, however, the external medium is a conductor, then a situation will be attained in which, while there are charges on the interface, the field will nowhere be zero. This problem is worked out in the appendix, Note 2, for the case of ohmic conductivity. It will be seen that in the resting frame of reference the solution is exactly the same as that in which the slab represents, by its interfaces, two plates of a battery with electromotive force vBh/c, where v is the velocity, B the magnetic induction and h the thickness of the slab. The material of the slab provides the internal resistance R_i of the battery and the medium outside provides the external resistance R_e. In the fixed frame of reference, the true field E in both the slab and external medium will be derivable from a potential,[19] since there is no time rate of change of the original field B at any point. The potential difference between the faces of the slab is given by P, where, just as in the case of a battery,

$$P = \frac{R_e}{R_e + R_i} \text{(E.m.f. of the battery)} = \frac{R_e}{R_e + R_i}\left(\frac{vBh}{c}\right). \qquad (1)$$

One or two remarks must be made concerning the significance of

[19] Except for the field of electromagnetic induction produced by the motion of the magnetic field arising from the current in the medium, which field is of the order of v^2/c^2 times the original magnetic induction B, when measured in the "fixed" frame of reference.

Of course, the actual force per unit charge on a particle moving with the matter, when measured in the fixed frame of reference, is $E + [vB/c]$, where E is the electric field.

this expression. In the form in which it has been derived, it applies strictly to a case of ohmic conductivity. Ohmic conductivity is limited by the two circumstances referred to in Appendix, Note 1, *viz.* (1) the fact that the field may be so high for the long mean free path that Ohm's law no longer applies even in the absence of a magnetic field, and (2) if a magnetic field is present, the whole nature of conductivity in the isotropic sense is modified. However, since there is no time rate of change of the original B, and so no curl of E at any point, the field will always be derivable from a potential except for the part arising from the motion of the currents generated by the motion of the matter as aforesaid, this part of the field depending upon v^2/c^2.

It will, at this stage, be convenient to recognize certain consequences which follow from the foregoing considerations. A charged particle, coming from infinity on one side of the slab and traveling to infinity on the other side, will gain no energy. Moreover, a particle circulating in an orbit which passes through the slab will gain no energy. A positive particle coming from infinity to the positive side of the slab will have lost energy. On passing through the center, it will have neither lost nor gained energy. In emerging from the negative side, it will have gained energy, but the gain gradually disappears as it continues its journey to infinity.

Alfvén's Theory of the Effect of Magnetic Storms.[20] In Alfvén's theory of the effect of magnetic storms on cosmic rays, the aforesaid alteration of energy in passing through a slab is invoked to determine an alteration of cosmic-ray intensity as the result of the rays shooting through a beam of ionized gas, which itself is shot out from a solar flare on the sun with a velocity determined by the velocity of ejection and the velocity of the sun's surface. As the beam of gas sweeps through space, the earth first finds itself on one side and then on the other side. If, on contact with the beam on one side, it finds itself at a potential higher than the normal, then, when on the other side, it finds itself at a potential lower than the normal. The cosmic rays approaching the beam are consequently reduced in energy in one case and increased in energy in the other. The results of this situation reflect themselves in the intensity in such a fashion that the intensity is increased by increasing the energy and is reduced by reducing the energy. According to Alfvén's calculation, the percentage increase or decrease at the top of the atmosphere is the same for all directions for those rays which have passed through the beam. The foregoing theory, in providing for possibilities of increase as well as of decrease of intensity in harmony with experimental observations, has, in this matter, the advantage over theories based upon alteration of the magnetic field in the earth's vicinity. The latter type of theory could explain a decrease of intensity at high latitudes and at sea level, but could not explain an increase, because the extra rays corresponding

[20] H. ALFVÉN, *Phys. Rev.*, Vol. 75, p. 1732 (1949).

to the increase would be unable to penetrate through the atmosphere to the earth. However, Alfvén's calculation seems to be in error in making the alteration of intensity at entrance to the atmosphere independent of the angle (in relation to the direction of the electric field) at which they are received, see Note 3. (Also H. ALFVÉN, "Cosmical Electrodynamics," Oxford University Press, 1950, pp. 216–217.)

One of the difficulties associated with the above theory, a difficulty recognized by Alfvén, is that even if we assume the beam to be as wide as 5×10^{12} cm. and to travel with a velocity of 2×10^{8} cm. per second, the magnetic field in the beam necessary to provide for the change of intensity in a typical case is 3×10^{-4} gauss. This is 150 times greater than the solar dipole field at the earth, even if one assumes for the sun a magnetic moment such as to give it a field of 50 gauss at the pole and, as already remarked, such a field is probably far too large.[21]

In order to obviate the difficulty arising from the smallness of the sun's magnetic field, Alfvén has invoked a principle, to be expounded more fully later, to the effect that highly conducting matter which has come from a region of intense magnetic field tends to carry the magnetic field along with it and thus provide, in the case of a beam of highly conducting gas, a magnetic intensity comparable with that experienced by the gas at the time when it left the flare. It is of interest to notice that in this case a particle traveling with the beam would experience no force of any kind. There would be no displacement of charge and no electric field. However, in a stationary frame of reference, there would be a field. In the case where the media are non-conducting, this field E is given by

$$E = -[vB]/c \tag{2}$$

measurements being made in the fixed frame of reference. The field is in part derivable from a potential [22] which, at great distances, is such as would be produced by an electric doublet of moment N, given by

$$N = -[vM]/c, \tag{3}$$

where M is the moment of the magnetic doublet to which, at great distances, the magnetized matter is equivalent.

In discussing the energy gained by a charged particle—a cosmic ray—when subject to the field E, we tread, however, on dangerous ground. The most certain line of attack is the following: First let us take the case where the medium external to our moving slab has zero conductivity, so that there are no currents in the steady state. In the *moving* system there is no electric field at all, and a charged particle cannot acquire any energy in this field; it can only have its momentum

[21] It would seem that in view of the possibility of very large departures from Ohm's law such calculations should be revised in the light of the actual probable situation as regards mean free path, etc.

[22] For a discussion of this whole matter, see W. F. G. SWANN, *Phys. Rev.*, Vol. 15, p. 169 (1920).

altered. Consider, for example, a particle starting at infinity and suppose that here the particle is moving parallel to the direction of motion of the slab, with a velocity u' as measured in the moving system, and that, as a result of the bending of its path in the magnetic field, it finally reaches the surface of the slab in a direction perpendicular thereto. It will still have a velocity u'. Its momentum in the direction of the x axis (considered parallel to v) will have changed by $-m_0u'/(1-u'^2/c^2)^{\frac{1}{2}}$. Its energy in the moving system will be unchanged. However, its energy in the fixed system will have changed by an amount which we can calculate from the relativity transformation. If

$$k = \frac{m_0c^2}{(1-u^2/c^2)^{\frac{1}{2}}}$$

so that $k - m_0c^2$ is the kinetic energy of the particle when at infinity, measured in the fixed system, and if dashed letters refer to the moving system, we have, when the particle is at infinity

$$k = \beta\left(k' + \frac{k'u'v}{c^2}\right),$$

where $\beta = (1-v^2/c^2)^{\frac{1}{2}}$.

When the particle has arrived at the slab, we shall have for k the value k_2 given by

$$k_2 = \beta k_2'.$$

Since $k' = k_2'$,

$$k_2 - k_1 = \beta\frac{k'u'v}{c^2},$$

and since $k_2 - k_1$ is the change of energy of the particle, we see that even if $u' = c$, the change would be small. If now we introduce conductivity into the space surrounding the slab, then since, in the moving system, this surrounding medium is in motion with velocity $-v$, a particle will experience the force $-[vB]/c$ per unit of charge. As a result of this, currents will flow, and this will bring about charges on the surfaces of the slab and a field in the slab. If E' is this field and if λ_1 and λ_2 are the conductivities just inside and outside the slab,[23] continuity of flow requires that

$$-\frac{vB'}{c}\lambda_2 = E'\lambda_1,$$

where B' is the value of the induction at the boundary, measured in the moving system. Thus [24]

$$E' = -\frac{\lambda_2}{\lambda_1}\frac{vB'}{c}. \qquad (4)$$

[23] For simplicity, we limit the case to one of ohmic conductivity.

[24] The expression for E' given by (4) seems peculiar in indicating that $E' = \infty$ when $\lambda_1 = 0$. The reason for this lies in the fact that we have supposed that the field outside the slab is zero. This amounts to treating the slab as of infinite extent. Actually, a field would

The field in the fixed system will be E, where

$$E = \beta\left(E' + \frac{vB'}{c}\right),$$

$$= \beta\frac{vB'}{c}\left(1 - \frac{\lambda_2}{\lambda_1}\right).$$

Since $\beta B'$ is the magnetic B as measured in the fixed system

$$E = \frac{vB}{c}\left(1 - \frac{\lambda_2}{\lambda_1}\right). \tag{5}$$

The field E' is everywhere derivable from a potential in the moving system since, in that system, there is no change with time of magnetic induction at any place. The potential difference between two points A and B is the line integral of E' along any mathematical path from A to B and, regardless of the path [25] taken by a particle in going from A to B, its alteration in kinetic energy will be determined by that difference of potential in the moving frame, and in the fixed frame it will only be slightly different in value.

It is of fundamental interest to observe that the actual possibility of a particle acquiring appreciable energy thus depends upon the existence of a conductivity in the space surrounding the slab, a point which does not seem to be recognized in Alfvén's presentation.

At first sight, the fact that (5) yields a finite value for E in the fixed system when $\lambda_2/\lambda_1 = 0$ may make it appear surprising that, for $\lambda_2 = 0$, a particle can gain no appreciable energy as measured in the fixed system. The apparently surprising conclusion is true, however. As remarked in the Appendix, Note 5, in the case of a particle moving in crossed electric and magnetic fields, we can always transform to a system of axes in which there is nothing but a magnetic field, provided that $E < B$, as it is in the present case where, with $\lambda_2/\lambda_1 = 0$, $E = vB/c$. In this transformed system, the particle describes a circle with constant energy, and in the original system it describes a cycloid with only slightly varying energy.

Magnetized Stars and Galaxies in Rectilinear Motion. Certain interesting features are presented by the motion of magnetized stars and galaxies. In the frame of motion there is nothing but a magnetic field

exist outside, although it would be small compared with the field inside. In the limit when λ_1 was zero, there would be no current and the steady state would be one in which $E_o' - vB'/c = 0$ just outside the slab, where E_o' is the field there. The equal and opposite charges on the two faces would therefore be such as to make $E_o' = vB'/c$ and the field E_i' inside would then determine a surface density σ such that $E_o' - E_i' = \sigma$, i.e., $vB'/c - E_i' = \sigma$ for one plate and $vB'/c - E_i' = -\sigma$ for the other. Of course, neither E_i' nor σ would be constant over the surfaces of the slab.

[25] Thus, in traveling from A to B, the particle will, in general, spiral around lines of magnetic force.

and therefore no change of energy for a charged particle moving in the vicinity of the star or galaxy. In the resting frame of reference a star, moving perpendicular to its magnetic axis, has an electric field which is partially derivable from a potential and the potential is that due to a doublet, as already stated, the relation between the moment N of the electric doublet and the moment M of the magnetic doublet being given by (3). No matter of great importance arises from the realization of this situation, and it is only mentioned because the potential differences obtainable from the electric doublet field alone would be very considerable, but the field due to it is modified in such a manner that practically no energy can be acquired by a cosmic ray particle as a result of the motion of such a galaxy or star, for the reasons already given.

Corollary on the Attraction of Magnetic Galaxies.[26] While the matter here concerned is not of immediate significance in relation to cosmic ray energies, it is worth while to observe that magnetic galaxies exert forces of attraction and repulsion on one another, these forces being merely the representatives of the forces between the currents responsible for the magnetic fields.

To take an illustration, consider a flat circular galaxy whose magnetic field is supplied by a current around its periphery, the radius of the galaxy being R and the magnetic field at the center, H. The galaxy is equivalent to a magnetic shell whose moment M is easily seen to be given by

$$M = R^3H/2.$$

The force F of attraction between two such galaxies suitably aligned is

$$F = \frac{6M^2}{r^4} = \frac{3}{2}\frac{R^6}{r^4}H^2,$$

when at a distance r apart.

If t is the time to attain a velocity v, and if m is the mass of the galaxy

$$\frac{3}{2}\frac{R^6}{r^4}\frac{H^2}{m}t = v.$$

If we put $R = 10^5$ light years, $r = 10R$, $m = 10^{42}$ grams, then, to make $v/c = 0.1$, we must have

$$t \sim 10^4 \text{ years if } H = 0.1,$$

$$t \sim 10^{12} \text{ years if } H = 10^{-5}.$$

The significance of these conclusions is sufficiently obvious and need not be elaborated upon.

Alfvén's Theory of Cosmic Ray Energies.[20] Alfvén has extended the foregoing ideas in an endeavor to account for cosmic ray energies. The theory concerns itself with particles which have already acquired reason-

[26] W. F. G. SWANN, JOUR. FRANKLIN INSTITUTE, Vol. 227, p. 621 (1939).

ably high energy and are circulating around the sun in orbits controlled by the sun's magnetic field. Suppose that under these conditions a beam of gas emerges from the sun. Alfvén argues that the field characteristic of the steady state we have discussed above does not establish itself instantaneously on account of the fact that the return currents flowing outside the beam (which return currents would certainly exist if there were a field external to the beam) would be attended with such large self-induction effects that they would be unable to grow to their steady state values in a short time. It is implied, in fact, that their attempt to grow would produce counteracting fields which would delay not only their own growth but, more primarily, the growth of the field which produced them. On the other hand, it is argued that if, after the steady state has been attained, we stop the beam of gas, the now established field in external space will die slowly, while the field in the space formerly occupied by the gas will die quickly. In the steady state, a particle coming from infinity and passing through the beam to infinity on the other side thereof would gain or lose no energy. If, however, it passes through the beam just after it starts, it is argued that it will experience only the field in the beam and will experience a change in energy. Suppose we consider the sign of charge and the direction of motion such that there is a loss. When the steady state has been established, a similar particle will experience no loss on the whole. If the beam is now stopped, however, it is argued that the field in the beam will disappear rapidly, while the external field will remain for a time, and this external field will, acting alone, provide an increase of energy of the particle in traveling from (essentially) infinity on one side to infinity on the other. In describing its orbit the particle, for all practical purposes, is supposed to come from and depart to infinity, but in describing the orbit it will, during the period of decay of the external field, gain energy each time it crosses the space where the beam was.

Insofar as the foregoing mechanism contributes to the general cosmic radiation observed on the earth, presumably it is assumed that beams of gas are continually being formed and are continually disappearing.

Now in the above connections, both as regards the theory of the effect of storms and the theory of the general cosmic radiation, there are certain rather subtle matters concerned with the time of establishment of the electric field, its nature in relation to a potential, and so forth. In Alfvén's paper [20] certain remarks are made concerning these matters, but it is not in all cases clear that the arguments are consistent with a strict interpretation of the laws of electrodynamics; and although the ultimate results following from a failure to distinguish between cases which are essentially different may, by mathematical accident, be true, it is important that, in a subject beset with so many pitfalls, a consistency of principles should be maintained. For these reasons, and in order to avoid interruption of the general trend of the text, the matters

in question have not been referred to in the above, but will be discussed with reasonable thoroughness in the Appendix, Note 4. Certain matters have already been discussed in the previous section.

Results Following from the Rotation of Magnetized Spheres. Another case invoking the motion of matter in a magnetic field is that of a magnetized sphere rotating about its axis of rotation.[27]

Here the motion of the matter in the magnetic field results in a force of the $[vB]/c$ type, which here results in a distribution of charge which gives rise to an electric field derivable from a potential. In the case where the external medium is a non-conductor, this potential is such that the difference of potential V between the axis and the point on the equator of the sphere is given by

$$V = B\omega a^2/2c, \tag{6}$$

where a is the radius of the sphere, B the magnetic induction and ω the angular velocity of rotation. In the case where the external medium is a conductor, currents will circulate through the sphere to the outside and back again. Again, there will be a field which is wholly derivable from a potential, but the potential difference concerned will be less than it is when the external medium is an insulator. It is to be remarked, moreover, that if the external medium does not obey Ohm's law, distributions of charge will result which again help to determine the field derivable from a potential but which complicate the whole problem considerably. Such distributions of charge would, under similar conditions, also arise in the problem of the moving slab of gas above cited.

For the simplest case, where the external medium is a non-conductor and for the case of a star of the size of the sun rotating with the sun's angular velocity and with a magnetic field such as to give 50 gauss at the pole, there will result a potential difference comparable with 3×10^9 volts between the axis and the equator. For a star such as was cited by H. W. Babcock [13,28] with a magnetic field of the order of 6000 gauss at the pole, and a radius about twice as large, the corresponding potential difference would be of the order of 10^{12} volts for the same angular velocity.

It is to be remarked that since the diminution of the potential difference in the above problem depends rather upon the ratio of the effective conductivity of the sphere to the total effective conductivity of the external medium, it is reasonable to suppose that the large value of the former in relation to the latter will result in potential differences comparable with those calculated for the case of zero external conductivity.

[27] The solution to this problem will be found in W. F. G. SWANN, "Unipolar Induction," Equation 18, *Phys. Rev.*, Vol. 15, p. 365 (1920), which also contains the experimental verification. The problem has also been worked out for a magnetized spheroid, under the writer's direction, by A. ROGNLEY, *Phys. Rev.*, Vol. 19, p. 609 (1922) and has been verified experimentally by E. O. Lawrence. J. M. Barnothy has used this mechanism as a source of cosmic ray energy (see "The Sun, a Unipolar Generator"—Echo Lake Cosmic-ray Symposium, paper 44a, 1949).

[28] H. W. BABCOCK, Pasadena Symposium on Cosmic Rays, June, 1948.

In thinking of a field such as would be produced by a rotating star, one has to observe that the potential difference between the equator and infinity is necessarily zero. However, a charged particle emerging from the pole and getting to infinity would there have an energy corresponding to the amount above calculated. Moreover, a particle emerging from the pole would have the best chance of avoiding hindrance in its journey by the effect of the magnetic field. A charged particle passing by such a star would, of course, gain no energy on the whole since, coming from a great distance and returning to a great distance from the star, its total potential change over the distance traveled would be zero.

It is of interest to observe that since, in (6), ωa represents the peripheral velocity, V is proportional to Ba for a given peripheral velocity. This raises the point that rotating galaxies endowed with magnetic fields can give rise to large line integrals of electromotive force.

Electric Fields Arising from Electromagnetic Induction. Although some of the problems already discussed present cases of electric fields arising partly from electromagnetic induction, they do not present such induction in its most simple form. Considering cases more clearly of the inductive type, I may refer to a mechanism which I proposed some seventeen years ago [29] and which started from the idea that the changing magnetic fields in sunspots could give rise to a line integral of electromotive force of large amount. A particular example was worked out, and since there has been some misunderstanding of the nature of this mechanism—possibly as a result of failure to read the original paper in detail—it may be well to enlarge to some extent upon the relevant details.

In general, if we have, let us say, a symmetrical situation in which a magnetic field in the direction of the axis of z is growing, there will be an electric field which, at any instant, is perpendicular to the radius from the center of symmetry drawn perpendicular to the axis of z. A charged particle starting to move in the changing field will not, in general, describe a very simple orbit. Its motion will be compounded from the effect due to the electric field and the $[vB]/c$ term of the magnetic field. In the paper cited, it is shown that the particle will only gain energy at any instant provided that, if at $t = 0$, $H_z = 0$, then at the instant concerned

$$\frac{d}{dt}(rU_\theta) \geqslant 0, \tag{7}$$

where H_z is the magnetic field at the point, U_θ is the vector potential perpendicular to the radius vector, and r is the distance from the center of symmetry. The condition (7) is shown to be the equivalent of

$$-(E_\theta - \tfrac{1}{2}rH_z/c) \geqslant 0, \tag{8}$$

[29] W. F. G. SWANN, *Phys. Rev.*, Vol. 43, p. 217 (1933).

where E_θ is the tangential field arising from electromagnetic induction and $\dot{r}$ is the radial velocity. There is one case which can be worked out in relatively simple form. In this case, starting from the beginning when the magnetic field is zero, the situation is adjusted so that the rate of growth of energy of the particle starting out at a distance r_o from the axis is such as to keep it continually moving in a circle at that distance r_o. As the energy increases the radial acceleration increases, but the magnetic field also increases so as just to balance it, and the orbit is a circle of constant radius but ever-increasing energy.

It will be seen from the above, and more explicitly from an examination of the paper, that it is *not large magnetic fields* which are helpful in accelerating particles by this mechanism, it is *rate of change of magnetic field*. Magnetic field itself is bad for the process and, indeed, in the example cited in the paper, the charged particle gains 2×10^{10} e.v. in one second from the instant when the supposed magnetic field was everywhere zero. At this time the field is no more than 2×10^{-3} gauss.

For the continuous generation of cosmic ray energy by a mechanism of the foregoing kind, it is natural to invoke, not drastic magnetic field production as in the case of sunspots, but rather magnetic field fluctuations of small amounts over wide areas in the star. Moreover, since the rate of change of magnetic fields is involved, large rate of change for very small times and such as to require no appreciable value in the magnetic field itself can be efficacious. Again, the direction of the rate of change is immaterial, so that fluctuating magnetic fields can be effective in each half of the cycle of fluctuations. A particular case of this kind of thing is one where the whole surface of a star is in a state of what we may call magnetic fluctuation, the average magnetic field in the outward direction being possibly zero in the statistical sense. Fluctuational phenomena will then, at individual instants, result in finite line integrals of the electric field around areas containing many of the sources of fluctuation.

The foregoing view has been criticized by Alfvén and by Teller, but I am unable to conclude that the criticisms are valid.[30] However, I will relegate the discussion of the details of this matter to the Appendix, Note 5.

Acquirement of Energy Through Electromagnetic Radiation. D. H. Menzel and W. W. Salisbury [31] have supposed an ingenious mechanism based upon the known existence of electromagnetic radiation from solar flares. If we consider a parallel beam of radiation coming out into space from the sun, we have an electric field and a magnetic field at right angles to each other, both being perpendicular to the direction of the beam.

[30] H. ALFVÉN, *Phys. Rev.*, Vol. 75, p. 1732 (1949); also H. ALFVÉN, "Cosmical Electrodynamics," Oxford University Press, 1950, pp. 228–231: E. TELLER, Echo Lake Cosmic-ray Symposium, June, 1949 (discussion of paper No. 39).

[31] *Nucleonics*, Vol. 2, No. 4.

If a charged particle coming from the outside enters at some place in the direction of the electric field, it will receive energy from that field if the direction is appropriate. For low energies the particle receives energy in a direction primarily transverse to the beam, but as the velocity of light is approached, the particle moves more and more in the direction of the beam. It receives energy by a process which mathematically is the equivalent of what is usually termed the pressure of radiation. The theory has been worked out in more detailed form by E. M. McMillan [32] who has calculated the motion of particles under the conditions in question.[33] We shall discuss the matter from the standpoint of McMillan's presentation.

The waves concerned are waves of low frequency supposed to be associated with solar flares. A difficulty is presented by high conductivity of space which tends to give to the said space an imaginary value for the refraction index and this has the physical effect of preventing waves of low frequency from penetrating the earth's ionosphere or even of traveling through the space between the sun and the ionosphere. McMillan adopts the hypothesis that the waves act on the very particles which are responsible for the spatial conductivity in such fashion as to cause the space to be swept clean of conductivity faster than it can be supplied by fresh ions from the corona, for example. The cleaned out space has a region of high conductivity ahead of it and constitutes what McMillan calls a "bubble"—a bubble of conductivity-free space. The wave trains coming into the bubble are reflected from the boundary where conductivity begins, but they are not reflected so as to retrace completely their original paths in such fashion as to set up stationary waves. They are reflected in large part at angles so large as not to destroy the resultant realization of a progressive wave train which assumes the responsibility of accelerating the particles. McMillan supposes that bubbles of this kind can thus act as accelerating regions in which particles can receive cosmic ray energies. Quoting from McMillan's paper as to the orders of magnitude involved:

> The following connection (with solar flares) is proposed. The flare initiates a large magnetic disturbance at the sun's surface; this is propagated through the corona, and when it reaches the surface of the latter a "wave bubble" is formed. Then ions are accelerated by the mechanism of Section II. Assuming, for

[32] E. M. MCMILLAN, *Phys. Rev.*, Vol. 79, p. 498 (1950).

[33] McMillan draws a distinction between this process of impartation of energy and that associated with the "pressure of radiation" on the basis that the radiation reaction terms are neglected in the calculation. However, I think that mathematically the impartation of the energy is exactly the equivalent of that involved in the pressure of radiation. That this is so may perhaps be most readily seen by examining the pressure of radiation from the standpoint of its impartation of momentum to an obstacle on which the radiation falls (see "The Pressure of Radiation," W. F. G. SWANN, *Phil. Mag.*, S. 6, Vol. 51, p. 584 (1925)). However, the point involved is not of much importance.

example, a sinusoidal wave of frequency 10 cycles per second and peak electric field of 10 volts per cm acting on protons, and applying the formulas of the last paragraph of Section II, it is found that an energy of 5×10^{10} ev can be imparted to the protons. They would move forward 9.4 wave-lengths during their acceleration, which would take place in a half-cycle of wave phase as seen by the particle. Electrons in the same wave field would tend to acquire still higher energies, but would move forward so far that the finite size of the bubble would be a limiting factor. Thus if the wave field is terminated at 10 wave-lengths, electrons starting at the most favorable phase (maximum field) would pick up only about 6×10^{9} ev. On the other hand, multiply charged heavy ions would acquire great energy; a completely stripped iron nucleus would be accelerated to a maximum of 6×10^{11} ev by the same field.

The chief difficulties in supposing that the general cosmic radiation can originate from solar flares according to the foregoing mechanism lie in the difficulty of explaining the isotropical nature of the observed radiation and its constancy. As regards these difficulties, appeal is made to the possible existence of an extensive magnetic field associated, however, with the general region of the sun. This field is supposed to be weak, but sufficiently extensive to curl up the paths of cosmic ray particles in such fashion as to prevent their escape into outer space and at the same time provide a basis for an "ergotic" condition such as is necessary to provide for the isotropical nature of the cosmic radiation within the magnetic field controlled region. The space is supposed to be fed by the solar flare mechanism discussed above and at the same time to experience a loss of cosmic rays by collision with nuclear particles in the space. The balance of the two processes determines the intensity of the radiation. It will be observed, however, that this balance is controlled by the time integral of the contributions from flares over long periods of time, so that the short period fluctuations iron out and provide for a more or less constant resultant intensity for the radiation.

Unsöld, on the basis of the known correlation between solar flares and sudden changes in cosmic ray intensity, has examined the possibilities regarding the origin of the cosmic radiation in such disturbances. On such a view, the contribution from the stars must be considered. At first sight one might find bases for believing that if the radiation is to originate in "flares," the contribution from the stars would be negligible; for if the sun is to represent a typical star, we might expect the contribution from the sun—which is so near to us—to outweigh the contribution of the stars to something like the extent that sunlight outweighs starlight. However, from a consideration of all the circumstances, Unsöld is driven to conclude that the sun is not a typical star in this matter, but is, in fact, a very inactive star, and he suggests that

the average activity of a star is so much larger than that of the sun that the contributions from stars actually dominate the situation as sources of the general cosmic radiation. In connection with such ideas, a general magnetic field for our whole galaxy has to be postulated as the confining agent which prevents the escape of the cosmic rays and which also, through its complicating action on the paths of the rays, provides for the ergotic condition necessary for the isotropic property of the radiation. Again we have a balance between loss of cosmic rays resulting from collisions with nuclear particles and gain of particles resulting from continual injection of such rays into the galaxy through the agency of the flares.

Such theories as those now under discussion, in confining cosmic radiation to the various galaxies, avoid the necessity of extending cosmic rays to the whole of intergalactic space, and so they avoid the difficulties which are inherent in such extension of the radiation and concerned with the enormous amount of energy which such extension would impute to the cosmic rays in the universe as a whole. This, as already stated, amounts to an energy far greater than the kinetic energy of all the matter in it; an energy less, in fact, than the whole "rest energy" of all the matter in the universe by only a few orders of magnitude.

CONCLUSION

In seeking an answer to the question of the origin of the cosmic radiation, we continually meet situations where processes which would give effects of but small magnitude when operated in laboratory dimensions can become of great potency on the cosmological scale. Even a thunderstorm, which is nothing more than an electrostatic machine operating through gravity as a prime motivator, is capable of generating a billion volts. When, therefore, we consider all of the potentialities in the greater universe, there is not much difficulty in finding many processes which might, under suitable conditions, give rise to cosmic ray energies. Usually such processes necessitate for their operation some cosmological process concerning which it may seem reasonable to suppose that it can occur, but in which the complexity of the system and the lack of knowledge of relevant variables is such that a mathematical solution for the problem in a form capable of speaking with certainty as to the possibilities and as to the orders of magnitude is beyond the range of our powers. Apart from this, there is no difficulty in finding many fruitful speculations. However, not until we have established that some cosmological process capable of giving cosmic rays not only "may" but "must" occur, and that it must occur in a fashion such as to give cosmic rays in the correct amount, energy distribution, etc., will we be able to feel that we have a satisfactory theory of the matter.

APPENDIX

Note 1. The Conductivity of Space

The elementary expression for the conductivity λ of a medium shows it to be the sum of two terms, one for each sign of carrier, with each term proportional to $n\lambda$, where n is the number of carriers per cc. and λ is the mean free path. Since for a completely ionized gas $n\lambda$ is independent of n, the conductivity of space with only one or two ions per cc. should be the same as that of a completely ionized gas at normal pressure and the same temperature. It results from this that the conductivity of intergalactic space should amount to as much as 2 per cent of the conductivity of copper.[34]

However, the existence of a conductivity which is independent of the field implies a condition in which the velocity gained over the mean free path is small compared with the velocity of temperature agitation. Now the mean free path for intergalactic space [34] is of the order 10^{12} cm., so that only for very small fields does an ohmic conductivity exist.

When an ohmic conductivity does not exist, space charges arise as a result of the flow of the currents. Thus, in the steady state, if i is the current density,

$$\operatorname{div} i = 0. \tag{1A}$$

If $i = \lambda E$, where λ is a constant independent of position and field

$$\lambda \operatorname{div} E = 0 \tag{2A}$$

and there is no space charge.

If λ is a function of E, however, (1A) no longer leads to (2A), and div E, and so the space charge, is not zero.

The presence of a magnetic field greatly complicates the significance of conductivity, and in such fashion as to hinder flow perpendicular to the magnetic lines of force.[34]

Note 2. Conducting Slab Moving in a Magnetic Field in a Medium Endowed with Ohmic Conductivity

The essential elements may be exhibited by the solution of the following problem: A uniform magnetic induction B exists in the direction of the axis of z. A slab of matter with its thickness h parallel to the axis of y and its plane in the x, z plane, moves with uniform velocity parallel to the axis of x. We wish to investigate the electric field inside and outside of the slab.

We shall, for convenience, assume ohmic conductivity, with specific conductivity λ_1 inside the slab and λ_2 outside. Let h be the thickness

[34] See H. ALFVÉN, "Cosmical Electrodynamics," Oxford University Press, 1950, p. 43–56.

of the slab and A its area. We shall assume that λ_1 is not altered appreciably by the motion. We shall, for convenience, but not of necessity, neglect quantities of the order v^2/c^2. We have continuity of current densities at the boundary surfaces between inside and outside. This involves a discontinuity of the electrodynamic force per unit charge inside and outside at the boundary.

Let us consider matters as viewed in the stationary frame of reference. If E_{20} and E_{10} refer to the fields outside and inside at the boundary, we have, of course, a surface density σ given by

$$E_{20} - E_{10} = \sigma.$$

Now since there is no change of magnetic induction with time at any point,[35] this surface density and its counterpart determine the electric field completely at all points in space, inside and outside. This field is, therefore, derivable from a potential.

If I is the total current passing through the plate, and if P is the potential difference between the surfaces, we have

$$I = \frac{P}{R_e}, \tag{3A}$$

where R_e is the ordinary external resistance which would be measured between two plates connected with the surfaces, if the slab itself were an insulator and the medium around retained its conducting properties. R_e is a quantity which requires considerable *complexity* in its calculation, but it is a matter of no *perplexity*.

From the continuity of current flow inside and outside the slab, considered now, of course, as a conductor, we have

$$I = \lambda_1 \left(E_{10} + \frac{vB}{c} \right) A. \tag{4A}$$

Now $hE_{10} = -P$, so that

$$I = -\lambda_1 \frac{P}{h} A + \lambda_1 \frac{vB}{c} A. \tag{5A}$$

Again, the quantity R_i, which would be measured as the internal resistance of the slab at rest, is

$$R_i = \frac{h}{A\lambda_1}.$$

Thus (5A) yields

$$I = -\frac{P}{R_i} + \frac{hvB}{R_i c} \tag{6A}$$

[35] Except for the change resulting from the motion of the currents generated by the slab, which change is proportional to v^2/c^2.

and (3A) and (6A) yield

$$\frac{P}{R_e} = -\frac{P}{R_i} + \frac{hvB}{R_i c},$$

$$P = \left(\frac{R_e}{R_e + R_i}\right)\left(\frac{vBh}{c}\right). \tag{7A}$$

This is the well known expression for the potential difference between the poles of a battery which has an e.m.f. (here equal to vBh/c) and external and internal resistances R_e and R_i, respectively, and our moving slab acts like such a battery.

In the case where the conductivity is not ohmic, the results are modified, but the field is still derivable from a potential in the most general case,[35] and the vB/c term appears in the light of a contributor of e.m.f. However, space charges are to be expected in regions other than the surfaces of the slab.

Note 3. On the Effect of Alteration of Cosmic Ray Energy on the Measured Intensities

Suppose the slab representing the beam of gas has its plane perpendicular to the axis of x drawn from left to right. Let us set up a telescope on the left hand side of the slab and point it in the direction defined by θ and φ, where θ is the angle with the axis of x and ϕ is measured around that axis. In the absence of the electric field, the number of rays passing through the telescope within the limits defined by $d\theta$ and $d\varphi$ will be $I \sin \theta d\theta d\varphi$, where I is the specific intensity. When the field is present, these rays will be transferred to an angle θ' and a range $d\theta' d\varphi$, so that the new intensity I' in the direction defined by θ' and φ will be such that

$$I' \sin \theta' d\theta' = I \sin \theta d\theta$$

$$\frac{I'}{I} = \frac{\sin \theta}{\sin \theta'} \frac{d\theta}{d\theta'}. \tag{8A}$$

Now if p represents resultant momentum, p_x and p_y the component momenta parallel, respectively, to the x axis and a line perpendicular to that axis in the direction determined by φ, and if T is the kinetic energy, neglecting the rest energy, we have as follows:

$$p = \frac{T}{c}; \qquad \sin \theta = \frac{p_y}{p}; \qquad \cos \theta = \frac{p_x}{p}; \tag{9A}$$

where, since the resultant velocity u is very nearly equal to c, we have assumed $p = m_e c/(1 - u^2/c^2)^{\frac{1}{2}}$.

Since p_y is unaltered by the field, we have, using (9A)

$$\frac{\sin\theta'}{\sin\theta} = \frac{p}{p+dp} = \frac{T}{T+dT}. \tag{10A}$$

Alfvén assumes

$$\frac{I'}{I} = \frac{\sin\theta}{\sin\theta'}$$

and so arrives at

$$\frac{I'}{I} = \frac{T+dT}{T}.$$

It would seem, however, that we must attend to $d\theta/d\theta'$.

We have, for a given p

$$\cos\theta d\theta = d(\sin\theta) = \frac{dp_y}{p}.$$

Hence, from (9A)

$$d\theta = \frac{dp_y}{p_x}$$

and

$$\frac{d\theta'}{d\theta} = \frac{p_x}{p_x+dp_x} = \frac{1}{1+\dfrac{dp_x}{p_x}}. \tag{11A}$$

Now

$$(p_x+dp_x)^2 + p_y^2 = (p+dp)^2$$
$$p_x^2 + p_y^2 = p^2.$$

Hence

$$2p_x dp_x = 2pdp$$
$$\frac{dp_x}{p_x} = \frac{pdp}{p_x^2} = \frac{1}{\cos^2\theta}\frac{dp}{p} = \frac{1}{\cos^2\theta}\frac{dT}{T}.$$

Hence, from (8A), (10A), and (11A)

$$\frac{I'}{I} = \left(\frac{T+dT}{T}\right)\left(1+\frac{1}{\cos^2\theta}\frac{dT}{T}\right) = 1+\left(1+\frac{1}{\cos^2\theta}\right)\frac{dT}{T}$$

so that I'/I depends on θ, and the radiation, if isotropic before passing through the slab, is no longer isotropic after passing through it.

Note 4. Certain Matters of a General Nature Pertaining to Electrodynamic Problems Involved in the Text

The Rate of Growth of the Steady State in the Problem of the Conducting Slab Moving in a Fixed Magnetic Field. Considering the case of the motion of a beam of gas (symbolized by our slab) in a magnetic field

arising from a stationary system, Alfvén argues that [20] until the lapse of a considerable time no field appears in the region outside of the stream because the currents to which it would give rise are associated with loops so large that self-induction would retard the growth of the steady state to an enormous extent.

Now while it is correct to assume that the steady state field outside the stream would not be established instantaneously, it is not, I think, on account of self-induction that this is so. Indeed, the whole concept of self-induction is one which has no exact meaning except in terms of currents which can be regarded as flowing in closed circuits in such a

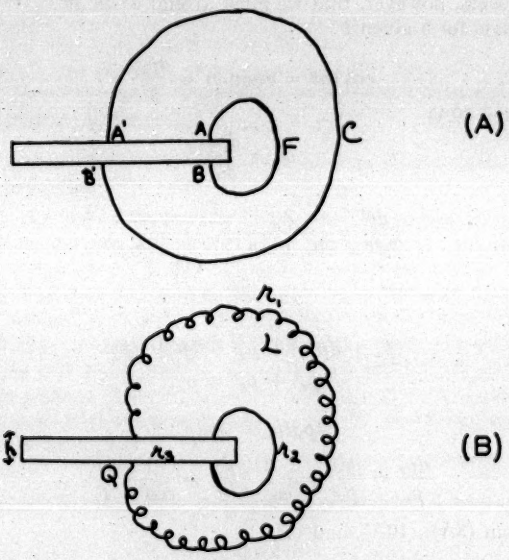

FIG. 1.

manner as to maintain constancy of flux of current over the cross-section of tubes of flow at all points of those tubes. It is true that if we speak of the total current density, including the displacement current density, then the continuity of flow over corresponding cross-sections is guaranteed at all times. However, an attempt to introduce the idea of self-induction to such a generalized current beclouds the issue. It is of interest to observe that for the case where there is continuity of flow of real current in the sense above understood, there will be meaning and self-consistency to Maxwell's equations without the $\partial E/\partial t$ terms of

those equations. It is only when the situation involves the motion of free charges, that the $\partial E/\partial T$ term becomes necessary to provide for the equation of continuity.[36]

To the extent that we can speak of closed currents growing with the time and without consideration of the $\partial E/\partial t$ term, what would happen would be the following: There would be a large line integral of electromotive force round such a curve as $A'CB'$, Fig. 1(A), due to any appreciable current flow in this path. On the other hand, there would be a much smaller line integral of electromotive force resulting from current flow in such paths as AFB. As a result, the currents in such paths as AFB would establish themselves to an approximation to the steady state much more rapidly than would the currents in paths such as $A'CB'$.

The situation may be symbolized by Fig. 1(B), where L is a self-inductance corresponding to the long path and the smaller loop is a path of much smaller inductance—an inductance which we shall neglect in order to emphasize the contrast. A shall be the area of the slab.

In terms of the notation of the figure, with c_1 as the appropriate capacity,

$$L\frac{di_1}{dt} + r_1 i_1 + \frac{Q}{c_1} = 0, \tag{12A}$$

$$r_2 i_2 + \frac{Q}{c_1} = 0, \tag{13A}$$

$$h\frac{(E + vB/c)}{r_3} = \frac{dQ}{dt}, \tag{14A}$$

$$AE = Q.$$

Hence

$$r_3\frac{dQ}{dt} + \frac{h}{A}Q = \frac{hvB}{c},$$

$$Q = \frac{AvB}{c}\left[1 - e^{-(h/Ar_3)t}\right]. \tag{15A}$$

Thus the time constant for the rise of Q and so of the potential difference between the faces of the slab is r_3c_1 and does not involve L.

As a matter of fact, the proper picture of the actual situation would appear to be one in which the slab is represented as a Hertzian oscillator, the separation of the charges corresponding to a single swing of the oscillator. In the case even of a conducting medium surrounding the slab, the currents travel out with approximately the velocity of light,[37]

[36] Of course, the $\partial E/\partial t$ term having been once introduced for this case, it must not be discarded when we revert to the case where no free charge exists.

[37] We have

$$\frac{1}{c}\left(i + \frac{\partial E}{\partial t}\right) = \text{Curl } H.$$ (*Continued on p. 150.*)

and the $\partial E/\partial t$ term plays a dominant role. The time taken for the current to establish itself at a given distance depends thus upon that distance.

Note 5. Concerning Certain Criticisms which Have Been Made Regarding the Generation of Cosmic-Ray Energies in Changing Magnetic Fields

The criticisms concerned refer in particular to the views expressed in the text under the heading, "Electric Fields Arising from Electromagnetic Induction," and originally formulated in a paper by the writer about seventeen years ago.[29] Although the picture of a sunspot was taken as illustrating the process, the original intention was not to limit the process to any such special case. However, since the idea of a sunspot has figured in discussion of this matter, I shall use the designation here. Alfvén writes: "A serious objection against this model is that the conductivity of the corona outside a sunspot is so high that the generator is short-circuited. In other words, the electric field must accelerate all particles in the region in question, but the available energy does not suffice to give them cosmic-ray energies. It should also be observed that this model is not reconcilable with a solar origin of the whole cosmic radiation, because fields much stronger and more extensive than sunspot fields must be assumed in order to account for the highest cosmic-ray energies."

Now concerning the above criticism, it must be remarked that, as shown in the original paper, it is only under the very special condition $E > B$ that we have guarantee of increase of energy of the charged particle. The *best* time for acceleration is when B is very small and not when it is large (as implied by Alfvén). Moreover, the conditions for acceleration do not occur necessarily at all parts of the spot at the same time. These matters are more particularly emphasized by the fact that in a sunspot we *do* observe an increasing magnetic field and it is clear that, while such a rate of change of field exists, there must be a line integral of E around closed circuits. The reason why the "generator"

If E is very small, as in a highly conducting medium

$$\frac{1}{c^2}\frac{\partial i}{\partial t} = \text{Curl}\left(\frac{1}{c}\frac{\partial H}{\partial t}\right) = -\text{ curl curl } E$$

$$-\frac{1}{c^2}\frac{\partial i}{\partial t} = \nabla^2 E - \text{grad div } E = \nabla^2 E - \text{grad } \rho.$$

Again, neglecting E,

$$\frac{1}{c^2}\frac{\partial i}{\partial t} = -\text{ grad } \rho$$

$$\frac{1}{c^2}\frac{\partial^2 i}{\partial t^2} = -\text{ grad}\frac{\partial \rho}{\partial t} = \text{grad div } i = \text{curl curl } i - \nabla^2 i.$$

If curl $i = 0$

$$\nabla^2 i - \frac{1}{c^2}\frac{\partial^2 i}{\partial t^2} = 0.$$

is not short-circuited, as Alfvén implies, is that, in general, and particularly when the magnetic induction is large, the particles are *not* accelerated. This is in accordance with the condition cited in the original paper. Incidentally, it must be remarked that in that paper the process of acceleration is not limited to a speculative possibility; the actual mathematical calculation of the case is carried through, the orbit—a very simple one—is determined, and the energy acquired is evaluated.

Further Comments on the Acceleration of Particles in Crossed Electromagnetic Fields. If a charged particle is moving in a crossed electric and magnetic field (E,B) and if the fields be perpendicular to the axis of x with E along the y axis and B along the z axis, we have, on transforming to any system (referred to by dashed letters) moving with velocity v along the x axis

$$E_y' = \beta\left(E_y - \frac{v}{c}B_z\right), \tag{16A}$$

$$B_z' = \beta\left(B_z - \frac{v}{c}E_y\right), \tag{17A}$$

where

$$\beta = (1 - v^2/c^2)^{-\frac{1}{2}}. \tag{18A}$$

If we choose v such that

$$v/c = E_y/B_z$$

we find $E_y' = 0$, and in this frame (which we shall call S') there is no electric field, but only a magnetic field, given, in fact, by

$$B_z' = \beta\left(B_z - \frac{E_y^2}{B_z}\right) = \frac{1}{\left(1 - \frac{E_y^2}{c^2B_z^2}\right)^{\frac{1}{2}}}\left[B_z - \frac{E_y^2}{B_z}\right]. \tag{19A}$$

In S' the particle describes a circle without any change of energy. In the stationary system S, we can calculate the change of energy as shown in the section on "Alfvén's Theory of the Effect of Magnetic Storms" and the change is of a fluctuating nature of an order v^2/c^2, and is negligible. The particle actually moves along the axis of x in a cycloid.

The foregoing argument applies to all cases where the electric field arises from the motion of magnetized matter, for in all such cases $E \sim (v/c)B$ and so $E < B$. I am perfectly familiar with this argument and have, in fact, used the example in my classes for many years. However, when $E > B$, as it can be in the case of a changing magnetic field arising from changing currents, the situation is different. Here since $B < E$ a transformation of the above kind is not possible. In fact, we can now transform away the magnetic field by (17A) in making

$$\frac{v}{c} = \frac{B_z}{E_y}$$

in which case $B_z' = 0$, and

$$E_y' = \beta\left(E_y - \frac{B_z^2}{E_y}\right) = \frac{1}{\left(1 - \frac{B_z^2}{c^2 E_y^2}\right)^{\frac{1}{2}}}\left[E_y - \frac{B_z^2}{E_y}\right]. \qquad (20A)$$

In this case the particle is accelerated along the axis of y in S' and therefore it is also accelerated along the axis of y in S and moves with constant velocity along the x axis, so that in actuality it describes a curve, which curve exemplifies the action of the magnetic field.

The Binding of Magnetic Fields to Moving Matter, and the Difficulty of Realizing a Rate of Change of B in a Highly Conducting Medium. It has been emphasized by Alfvén that matter originating in a magnetic field and moving out of it tends to carry the field with it, so that it is customary to speak of the freezing of the lines of force in the moving matter. The origin of this phenomenon, as derived from the electromagnetic equations, is perhaps not very obvious intuitively, but there is, I think, a way in which we can look at it so as to make the matter understandable in relatively elementary terms.

Considering, for simplicity, the case of a perfect conductor, we have to realize that in such a medium there can never be any electric field in the frame of reference of the conductor.[38] Now from this fact arises a rather astonishing conclusion that there can be no line integrals of electric field around any curve drawn in a perfect conductor, and consequently there can never be any time rate of change of a magnetic field in a perfect conductor. Consider then a piece of a perfect conductor which exists in a magnetic field, let us say, of external origin. Suppose that we move the conductor to a place where the aforesaid magnetic field of external origin has a different value. It is necessary for the conductor to arrange that there shall be no change of resulting magnetic field anywhere. As a result, every diminution or increase of the field produced by external causes at any point, either as a result of motion or as a result of changes of the currents producing the external field, must be balanced by the production of a compensating field resulting from currents generated in the piece of matter itself under consideration. The piece of matter is always able to generate internal currents to accomplish this end. Thus, if the aforesaid piece of matter moves completely out of the region of the original magnetic field produced by external forces, it is still to be found with a magnetic field of its own creation which has, at every point within it, the same value as

[38] A small reservation on this statement must be made as follows: When currents flow in the conductor, they produce magnetic fields which, through the term $[vB]/c$, distort the flow of the current, bringing about thereby a distribution of charge which results in a final state of equilibrium. This is nothing more than the Hall effect as applied to the magnetic field produced by a current operating on that current itself. The effect is, in general, small and can always be superposed in imagination upon the considerations cited above.

existed at that point when it was in the magnetic field of external origin. If the substance is not a perfect conductor, then, in course of time, the current responsible for the perpetuation of the magnetic field as aforesaid diminishes on account of the resistance, so that eventually the matter loses its magnetic field. However, in the case of a piece of matter of large size, the loss of the magnetic field is a slow business, since the size determines the inductive effect which dominates the situation to a large extent and retards the resistance effect. It is thus very hard for a large body to lose its magnetic field. To take an illustration,[39] if we consider a sphere the size of the earth originally permanently magnetized, for example, and if we should imagine the temperature raised suddenly in an attempt to destroy this magnetism, the induced currents set up as a result would tend to perpetuate the magnetic field, and if the conductivity of the sphere were equal to that of copper, about three million years would elapse before the magnetic fields had fallen to one third of their original value. The time constant is inversely proportional to the resistivity of the medium, so that if we desired the magnetic field to fall to one-third of its original value in an hour, it would be necessary to have a specific resistance about 2.7×10^{10} times the specific resistance of copper. In other words, we should have to have a specific resistance of about 3×10^4 ohms per cm.^{3}.

A Mechanism which Permits Change of Magnetic Flux Through a Fixed Area. Although the matter in the above illustration has difficulty in losing its magnetic field, the mutual action of the current elements associated with the current flowing in the matter is one of repulsion and is such as to bring about a spread in the dimensions of the currents, and so of the matter, associated with them. We can understand the phenomenon in its simplest form by considering a thin circular elastic wire with a current in it. Let us consider the case where we can neglect potential energy due to elastic strain. Let r be the instantaneous radius of the ring, M its mass and L the self-inductance. The kinetic energy T is

$$T = \tfrac{1}{2}Mr^2 + \tfrac{1}{2}Li^2, \tag{21A}$$

where i is the current.

Lagrange's equations give, for a non-dissipative system,

$$\frac{d}{dt}\left(\frac{\partial T}{\partial \dot{r}}\right) - \frac{\partial T}{\partial r} = 0, \tag{22A}$$

$$\frac{d}{dt}\left(\frac{\partial T}{\partial \dot{i}}\right) = 0. \tag{23A}$$

Equation (23A) yields

$$\frac{d}{dt}(Li) = 0$$

[39] See W. F. G. SWANN, *Jour. Wash. Acad. Sci.*, Vol. 11, p. 275 (1921).

so that Li is constant. The constant is equal to the initial magnetic flux N through the coil.

$$Li = N. \tag{24A}$$

Equation (22A) yields

$$M\ddot{r} - \frac{i^2}{2}\frac{\partial L}{\partial r} = 0$$

so that from (24A)

$$M\ddot{r} - \frac{N^2}{2L^2}\frac{\partial L}{\partial r} = 0.$$

Since $L \sim r$ for a wire of finite cross-section,

$$\frac{Md^2r}{dt^2} \sim \frac{N^2}{r^2}.$$

If τ is the time for the ring to expand from r_o to nr_o, we have, during τ,

$$\frac{d^2r}{dt^2} > \frac{N^2}{nr_o^2M}$$

$$nr_o > \frac{N^2\tau^2}{2nr_o^2M} + r_o$$

$$\tau < \frac{[2n(n-1)r_o^3M]^{\frac{1}{2}}}{N}.$$

Thus this time τ is not a quantity which is increased, but rather is reduced by a large value of N.

To sum up the situation, (24A) shows that the total flux through the circle remains constant as it expands, but the flux through a circuit in space diminishes. There is thus an e.m.f. around such a circuit and this is the e.m.f. which becomes available for accelerating charged particles.

In the case of a highly conducting medium, we must be careful about asserting the existence of line integrals of e.m.f. in the medium itself, for the reasons stated earlier. However, the matter with its circulating currents can produce change of magnetic flux in regions external to the matter, or rather, in regions where there is not enough matter to provide such conductivity as would reduce the field sensibly to zero.

The self-repulsion effect discussed above and accompanied by the expansion of the matter can, therefore, permit the operation of electromagnetic induction and the acceleration of charged particles in spite of the inertia opposing change of magnetic fields in the case of a highly conducting body of unalterable size. It is possible that this phenomenon can play a part in sunspot magnetic fields. It is possible also that it can play a part in many other manifestations of solar activity where a piece of matter is hurled out of a region where it was exposed to a magnetic field, is caused to generate its own magnetic field and then

enabled to produce electromagnetic inductive effects through the expansion under its own forces in the manner aforesaid. Such electromagnetic induction can then give rise to cosmic ray energies under suitable conditions.

Unsöld has, on an empirical basis, founded upon the correlation of electromagnetic radiation and change of cosmic ray intensity associated with solar flares, been led to postulate that such flares in the sun and in the stars may be the birthplaces of cosmic rays. The foregoing suggestion provides a possible mechanism by which this may come about.[40] Of course, it will be realized that such mechanisms are all particular cases of the general idea proposed by the present writer some years ago and illustrated by the possibilities inherent in the changing magnetic field in stellar situations analogous to those prevailing in sunspots.

[40] Unsöld has called attention to the fact that the cosmic ray anomaly appears later than the flare and by a time which is comparable with that measured as the time for masses of matter hurled from the sun's surface to return thereto in another place. Bearing in mind that the matter coming from the flare carries a magnetic field with it, Unsöld has suggested that possibly the splashing of matter back to the surface and the consequent destruction of the magnetic field may be responsible for the emission of the cosmic rays. The mechanism proposed above is one by which such a process can be realized in consistency with the laws of electrodynamics.

PROGRESS OF THE PHYSICS OF SOLIDS

BY

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1. INTRODUCTION

The unique form of crystalline solids has attracted interest and speculation since the earliest days of modern science. Perhaps the most dramatic example of this is given by Dürer's Renaissance wood carving "Melancholia" in which the outstanding mysteries of nature are portrayed in allegorical form. Among them is a large crystal showing well defined geometrical habit.

The study of crystalline solids has passed through three major stages of development and a fourth period seems to be drawing to its climax at about the time this is written. The four periods correspond to the development of the following topics:

(1) Macroscopic symmetry properties
(2) Lattice theory and lattice models
(3) Application of atomic theory to the determination of properties of perfect crystals
(4) Development of the theory of nearly perfect crystals.

The purpose of this brief article is to place emphasis upon the fourth of these stages of development, which, as stated above, is probably achieving its climax at the present time. Much of the fundamental research in the field of solids during the next decade will deal with the problem of carrying this development to its logical conclusion and in integrating its results with such applied field as metallurgy and ceramics.

2. MACROSCOPIC SYMMETRY PROPERTIES

The first period, which extended from the dawn of science to late in the last century, was that in which the properties of crystals were classified on a purely phenomenological basis with outstanding emphasis on the macroscopic symmetry properties. The accomplishments of this period of physical interest are probably best summarized in Voigt's classic *Lehrbuch der Kristallphysik*. It was recognized as early as the seventeenth century (Steno, Hooke, Bartholinus) that crystals possess elements of symmetry, that is, have identical physical properties in different symmetrically related directions. A thorough study of the symmetry characteristics showed that there are thirty-two *classes* of crystals (Rome de Lisle, Haüy, Weiss, Hessel), when viewed from the standpoint of the groups of motions which will send the symmetrically

equivalent directions into one another. The thirty-two classes correspond to the thirty-two self-consistent sets, or groups, of rotations and reflections which can be constructed from the following basic symmetry elements, all of which leave at least one point of the crystal fixed: Rotations about an axis through 0°, 60°, 90°, and integer multiples of these; rotations through these angles followed by reflections in a plane normal to the axis of rotation (rotary reflections); reflections in fixed planes; and finally reflection in a point (inversion center) in such a way that the coordinates of all points are reversed in sign. The systematic investigation of this aspect of crystals made it possible to describe in a careful and accurate manner such topics as piezoelectricity, pyroelectricity, double refraction and circular refraction.

3. LATTICE THEORY

The second major period of the subject, which centers about the development of lattice theory, began early in the 19th century when Bravais, following earlier leads, observed that one could understand the limitations on the symmetry elements which are observed in crystals if one assumed that crystals possess a lattice structure. In other words he assumed that a crystal is composed of identical cells having the form of a parallelopiped which are stacked in a space-filling way that possesses the translational symmetry of a honeycomb. It required little imagination to assume that the fundamental parallelopiped or *cell* contains only one, or at least a small number of the chemical molecules of which the material is composed. The period came to its climax in 1913 when Laue, Friedrich and Knipping observed that X-rays are diffracted by crystals in just the manner that would be expected if X-rays are electromagnetic waves and if crystals actually possess the lattice structure assumed by Bravais. Laue's discovery not only provided a tool for determining the arrangements of atoms in crystals, but also made it possible to determine the wave-lengths associated with all forms of wave-like radiations which have wave-lengths comparable to atomic dimensions, such as those of beams of gamma rays, electrons, atoms, molecules, and neutrons.

Between the work of Bravais and that of Laue lay an extensive period of activity in which the symmetry properties of three dimensional lattices were analysed and classified. Barlow, Federow and Schoenfliess found independently that there are 230 types of space lattice if they are classified on the basis of their symmetry characteristics, translational symmetry being included as well as rotational.

4. QUANTUM MECHANICAL TREATMENT OF PERFECT CRYSTALS

The third period centers about the development of the theory of ideally perfect crystals on the basis of atomic mechanics. Perhaps the land-mark which indicated the introduction of this period is the work

of H. A. Lorentz on the refraction of light by insulating crystalline media. Lorentz found that he could account for the variation of the index of refraction with wave-length in a very simple manner if he assumed that solids contain electrons which are bound to fixed positions with harmonic forces. His success stimulated other investigators to attempt to construct simple models of the various kinds of solid.

The earlier phenomenological work had recognized four principal types of solid, namely: (1) metals and alloys, (2) ionic crystals or salts, (3) valence crystals or abrasives, such as diamond and silicon carbide, and (4) molecular crystals, such as the organic crystals which have a very low melting and boiling point. Early in this century varying success was achieved in attempts to construct appropriate atomic models for these types of solid. For example, Drude proposed a model of a metal in which the valence electrons were treated as if they constituted a perfect gas which flowed in the interstices between atoms of the lattice. The finite electrical resistivity of metals was related to the mean free path for collisions between electrons and atoms. This model, which has retained much of its usefulness, was generalized first by H. A. Lorentz. He treated the statistical properties of the gas more completely than Drude with the use of Boltzmann's development of classical statistical mechanics. It was generalized still further by Sommerfeld who replaced the classical statistical distribution of velocities with that of Fermi and Dirac, which takes into account the influence of the Pauli exclusion principle upon the motion of electrons.

Similarly, Madelung suggested that the salts, such as the alkali halides, could be treated by regarding them as neutral lattice arrays of point ions. With remarkable insight, he actually proposed the structure for sodium chloride which subsequent X-ray investigations demonstrated to be correct. He found that the major part of the energy of cohesion of salts could be explained in terms of the simple coulomb attraction between the point ions. Born generalized Madelung's treatment by including repulsive forces between the ions. The inclusion of repulsive terms, which are important for the observed interionic spacing, made it possible to treat many of the properties of ionic lattices from essentially first principles. In fact the rapid development of the theory of ionic crystals prior to 1920 did much to focus attention upon the atomic theory of solids, for it became evident that these materials provided exceedingly good systems both on which to apply the newly developing theories of atomic dynamics and from which to deduce fundamental laws.

Very little explicit theoretical work was carried out on valence crystals and molecular crystals before the development of wave mechanics. It was recognized that the forces of attraction between the molecules in molecular solids were undoubtedly identical with the attractive forces first described by van der Waals as a result of the in-

vestigation of the properties of almost perfect gases which condense at normal or very low temperatures. The origin of the difference in the cohesive properties of valence crystals and other materials was a mystery.

The third period, related to the study of perfect crystals, reached its climax in the decade between 1925 and 1935, following the development of quantum or wave mechanics in the years extending from 1925 and 1927. It was found possible to construct a unified picture of all of the types of solid so that the earlier models of particular solids, such as those of Drude and Madelung, appeared as special cases in a more general frame-work. The general theory of solids can be discussed from several approximations, corresponding to different stages of accuracy and sophistication. One of the most profitable of these is the *band theory* which evolved at the hands of a number of investigators, most notably Bloch, Peierls, Bethe, Wilson, Wigner, Slater, Mott, Jones and the writer. This approximation starts from the assumption that each electron in the solid can be assigned its own characteristic energy and wave function and that the effects of electron interaction can be treated as a correction which does not alter the principal qualitative properties of solids. With this assumption, the Schrödinger equation provides a system of energy levels for the electrons in a crystal. These levels, in contrast to the widely separated discrete levels of an atom or molecule, are grouped into quasi-continuous bands. Each band contains as many states as there are unit cells in the crystal and is usually several electron volts in width. In a sense there is a close correspondence between the individual bands, regarded as units, and the atomic or molecular levels. The bands can be regarded as if derived from the atomic levels by the spreading of the latter as the atoms overlap to form a solid.

The bands of levels may be separated from one another, in which case the total spectrum consists of quasi-continuous regions separated by gaps, or forbidden regions. Or the bands may overlap one another, to a greater or lesser extent, in which case the spectrum is quasi-continuous, starting with the bottom of the lowest band and continuing upward.

The electrons of the solid occupy the levels of the bands in accordance with the Pauli exclusion principle so that only one electron is associated with each state. The case in which the top of the occupied levels borders unoccupied levels continuously, as when only part of a band is occupied or when the bands overlap, corresponds to a metal, since the electrons may be excited (accelerated) in an arbitrarily weak electric field. On the other hand, the case in which the bands are separated by gaps and in which the electrons occupy a set of bands completely in such a way that the top of the occupied region coincides with the top of one of the bands, which is separated by a forbidden region from the next band, corresponds to an insulator. For in this case a strong field is required to excite any of the electrons and make the system conducting, much as in the case of a dense gas.

The band theory explains the fact that many materials have properties intermediate between those of ideal insulators and ideal metals. Solids of this kind, such as bismuth, graphite, silicon and germanium, correspond to cases in which the bands either overlap by a very small amount, so that the materials are metals with poor conducting properties (bismuth and graphite), or are insulators with poor insulating properties (silicon and germanium).

The band theory has had a very large number of additional triumphs. For example, it has provided a clear explanation of the fact that many solids which have an electronic conductivity behave as if the carriers were positively rather than negatively charged. Investigation shows that current-carrying electrons which occupy levels near the top of a nearly full band behave like positive charges. All cases in which the positive characteristics occur in practice can be shown to be ones in which the levels are filled in just such a manner that there are vacant states (*holes*) near the top of the filled band. It is conventional to classify such cases by ascribing the conductivity to holes in the electron distribution in order to distinguish them from examples in which the electronic carrier behaves as if it had a negative charge.

The band theory is based on solutions of the Schrödinger equation which are obtained under the assumption that the detailed coulomb interaction between electrons can be replaced by a simple average, so that each electron moves in a fixed potential field. This approximation, though very good for descriptive and semi-quantitative purposes, is not precise and must be corrected if an exact solution of the equation of motions is desired. Unfortunately the process of correction is very difficult and has been carried out with moderate precision only in a few simple substances, such as the simple salts, molecular crystals and alkali metals. In such cases the theory provides a good quantitative description of characteristics such as the lattice spacing and cohesive energy. The problem of treating the electron-electron interaction with reasonable accuracy is the greatest obstacle in the path of using wave mechanical methods to compute the properties of most solids of practical interest from first principles. In fact the difficulties of treating the many-body problem accurately, represent the greatest impediment to the development of theoretical physics and chemistry as a whole at the present time.

5. IMPERFECT CRYSTALS

Once the bulk properties of perfect crystals were understood with reasonable clarity, attention became focussed on the properties of imperfect crystals. This transition in endeavor was not a discontinuous one, for the imperfections in crystals had been of interest ever since the study of these materials became systematized. In fact many important steps in the formulation of the study of imperfect crystals were

made in the period between 1905 and 1935 when the third stage in the development of crystal physics was ripening. For example, prior to World War I, Baedeker made a careful analysis of the influence of excess iodine on the electrical properties of cuprous iodide, thereby anticipating much of the modern work on semi-conductors. Similarly during the 1920's such outstanding investigators as Przibram, Pohl, Gudden, Smekal, and Schottky investigated the electrical, optical and mechanical properties of impure and imperfect insulators, placing much emphasis on the salts, whereas other investigators such as G. I. Taylor, Andrade, Polanyi, Schmid, Sachs, Orowan and Becker studied the plastic properties of the most perfect single crystals of metals which could be obtained. It was, however, only after the development of wave mechanics and its consequences, such as the band theory described above, that one could hope to approach these intricate problems with the degree of confidence requisite for a sustained and successful attack.

As in previous stages of development, the initial progress consisted in the classification of observations and in the construction of models which would correlate the observations in a portion of the field. Little was done to correlate the field as a whole during this period. In fact the extent to which correlation was possible was almost unsuspected among the great body of investigators. Smekal pointed out in the late 1920's that such a correlation would prove possible once the connection between mechanical, optical and electrical properties of salts became clear. He attempted such a correlation on the basis of the concept of *Lockerstellen* (literally spongy regions); however this concept was not sufficiently precise to provide a true rallying point for the development of the field. It has become clear within the last few years, however, that there is an underlying unity to the subject of imperfect crystals, much as Smekal suggested, and that the models which were introduced to explain individual effects bear a close relationship. At the time this is written, only the bare outlines of the interrelation are defined; another decade or so of work will be required before the quantitative aspects of the subject are revealed with full clarity.

Space does not permit a thorough discussion of the properties of imperfect crystal. It must suffice to describe the principal types of imperfections which have been discovered to date and to indicate the interrelation between them. As in the introduction, we shall consider the ideally perfect crystal to be a specimen in which the lattice network is perfect in the sense that the parallelopipedal cells are perfectly stacked and are filled in an identical manner with the constituent atoms of the lattice. Moreover, it will be assumed that the crystal is at the absolute zero of temperature so that the lattice is as quiescent as is physically possible, only the zero-point oscillations of the crystal being stimulated. Within this structure, it appears possible to introduce

six primary imperfections and *three types* of *secondary* or *transient imperfections.*

The primary imperfections are as follows:

(1) *Phonons.* These are the quantized waves of lattice vibration which are generated when the crystal transmits sound and when its temperature is raised from the absolute zero, so that the atoms of the lattice undergo thermal oscillation. The amplitudes of the possible vibrational modes of the lattice are not continuous, as classical mechanics would suggest, but are limited to discrete or quantized values. There is a close correspondence between phonons, or vibrational quanta of a crystal, and photons, the electromagnetic vibrational quanta of a *hohlraum.* The phonons introduce a secondary periodicity into the lattice, associated with the waves of vibration, over and above the normal periodicity.

Phonons may interact with one another because the forces between atoms are not perfectly harmonic. This interaction explains the fact that thermal agitation diffuses through a crystal in the well-recognized manner of heat flow, instead of moving with constant velocity in the manner of ordinary sound waves. The interaction also causes sound waves, which lie at the low frequency end of the vibrational spectrum of the lattice, to become attenuated after travelling a sufficient distance.

One of the very important effects of the interaction between thermally induced phonons is the production of localized concentrations of vibrational energy, or thermal fluctuations.

(2) *Vacant Lattice Sites and Interstitial Atoms.* At any finite temperature the perfect lattice becomes the seat of disorder, which has the effect of increasing the randomness required thermodynamically by increased temperature. One of the standard indications of such disorder is the production of *lattice defects.* The most simple of these are interstitial atoms and vacant sites. The first may be formed by migration of atoms from the surface of the crystal into the interstitial regions between the atoms or ions in the interior; the second by migration of atoms from normal positions in the interior to the surface (or to interstitial positions) to form vacant positions. These imperfections migrate about the crystal under the action of thermal fluctuations, that is under interaction with phonons, and permit migrational motion to the atoms of the bulk material. In this way the imperfections permit diffusion and electrolytic currents. In fact they were introduced first by Frenkel to explain diffusion and electrolytic conductivity in ionic crystals and have since gained wider use and recognition in the entire field. It is known by measurement, for example, that the alkali halides possess one vacant site in 10,000 at the melting point, whereas the corresponding number is of the order of one per cent in the silver halides.

(3) *Free Electrons and Holes.* The ideally perfect insulator possesses neither free electrons nor holes. However these carriers may be intro-

duced in a number of ways. For example, they may be introduced by irradiating the crystal with light or ionizing particles, such as alpha rays, which excite electrons from the filled bands to the empty bands, by applying a strong electric field which frees electrons from the atoms, by adding foreign atoms which release electrons to the lattice or by heating the specimen so that thermal fluctuations supply the needed excitation energy. Insulators in which free carriers appear become electronic conductors. The conductivity is called photo-conductivity if induced by light, breakdown conductivity if induced by an electric field, impurity-induced semi-conductivity if produced by impurities, and intrinsic semi-conductivity if generated by phonons in the perfect lattice.

(4) *Excitons.* Consider an insulating crystal in which a free electron and a hole have been produced. Since the hole is associated with a region of the crystal from which an electron has been removed, this region has a net positive charge and may attract the electron. In general the electron and hole possess a large number of states of motion in which they are bound together. Such states are analogous to the discrete states of a hydrogen atom, formed by the bonding of an electron to a proton. They are commonly called *exciton states.* Since the excitation may pass from one region of the crystal to another, it is convenient to regard the excitation as a type of uncharged particle, commonly called an *exciton.* An alternative way of looking upon the exciton, which is particularly profitable in molecular and ideal ionic solids, is to take the viewpoint that one of the constituent atoms or ions is excited and that the energy of excitation may be transferred from one constituent to its neighbor as a result of the close coupling between the two. Excitons may be generated by optical or thermal excitation or by bombarding the material with ionizing particles, such as alpha or beta rays. Since the exciton does not carry a charge, its presence and migrational properties can be determined only by indirect means, that is by the influence it has on the constituents of the crystal. Thus far the best information concerning these properties has been obtained from a study of the luminescent and photoelectric phenomena induced in crystals as a result of the production of excitons.

(5) *Impurity Atoms.* Impurities occur in all crystals, frequently in spite of the best efforts to exclude them. In many cases, they are added in carefully controlled amounts to impart special properties. For example, as mentioned in (3), an insulator may be transformed into a semi-conductor by adding impurities. In addition the impurities may impart special optical, electrolytic, or mechanical properties. Many of the most useful luminescent or photoconducting crystals derive their interesting characteristics from impurities whose electrons are excited or freed by light. The crystals are luminescent if the impurity returns to its ground state with the emission of light. A number of

the most interesting properties of alloys are derived from relatively small additions.

(6) *Dislocations.* There is ample evidence that ordinary crystal lattices possess a type of disregistry which cannot be interpreted on the assumption that individual atoms are independently out of place, as when interstitial atoms or vacancies are formed. Instead, the evidence requires the assumption that a large number of atoms are *dislocated* in a closely correlated manner. Those imperfections, which are termed *dislocations*, were first introduced by Prandtl, Taylor and Orowan to explain the plastic properties of crystals. It is now recognized, however, that they play an exceedingly important role in connection with essentially all properties of imperfect crystals. They would have been introduced in due course of time as a result of other investigations, even though their influence on the plastic properties is probably the most spectacular one.

An important elementary type of dislocation can be visualized in the following manner. Imagine that a closed curve is drawn within the solid. Assume that a cut is made over a surface which is bounded by this curve. Next, imagine that the portion of the lattice on one side of the cut is displaced relative to the other by a distance d in any direction, the relative displacement being the same over the entire surface. Forces are required to produce this displacement because of the elasticity of the medium. If the two sides of the surface are pushed together, imagine that material is removed so as to make a good fit. If they are pushed in opposite directions, imagine that material is added again to make a good fit. Following this suppose the surfaces are fastened together, and the forces producing the displacement removed. The crystal then possesses a permanent, internal distortion pattern (or dislocation) which is characterized by the curve and surface chosen and by the displacement vector d. The dislocation pattern is simplest when d corresponds to an edge, or vector combination of the edges, of the unit cell of the lattice. In this case the lattice is in registry over all portions of the surface where the cut was made, except near its boundaries, that is, near the curve originally selected. It can be shown that the distortional field is then independent of the surface chosen, and depends only upon the curve bounding the surface and the displacement vector d.

Dislocations can apparently be generated in practice in three important ways: (1) As accidents during growth. In fact F. C. Frank has shown that a number of dislocations are probably necessary to promote crystal growth. (2) By precipitation of vacant lattice sites during cooling if the crystal is grown from the melt. (3) By multiplication of existing dislocation when the crystal is deformed plastically.

Dislocations possess a very large number of interesting properties, which are probably only partly appreciated at the present time. The most important of these, recognized thus far, are as follows:

(*a*) They can be placed in motion, when the proper geometrical pattern prevails, by stresses that are very small compared to those which would be required to produce plastic flow in a perfect crystal.

(*b*) One consequence of their motion is the production of shearing strain, so that they can produce shear flow for very low stresses.

(*c*) They can act as sources or sinks for vacant lattice sites and interstitial atoms in almost unlimited quantities. As a result they play a very important role in maintaining an equilibrium density of lattice defects during diffusion or electrolytic conductivity.

(*d*) They apparently produce local heating of the lattice when placed in motion, so that disorder is stimulated and lattice defects are generated.

(*e*) It seems probable that the proper configuration of dislocations renders the lattice weak when placed in tensile stress, so that they contribute to the low rupture strength of real crystals.

(*f*) They represent distorted regions where electrons, holes and excitons may be generated more easily than in the perfect crystal.

In addition to the foregoing six primary imperfections, the crystal may possess transient imperfections, produced internally or introduced externally. There are three general categories of this type:

(1) *Light Quanta.* These may extend over any part of the frequency spectrum from the radio to the gamma range. They may pass through the solid without producing effects, or they may interact.

(2) *Charged Particles.* Cathode rays, alpha rays, beta rays, mesons, and similar charged radiations fall in this category.

(3) *Neutral Particles.* Neutrons are the most prominent of these of interest; however neutrinos and neutral mesons may be added for completeness. Although it may appear to the reader that the addition of this second category of imperfection is somewhat arbitrary, it actually fits very naturally into the scheme of imperfections since the transient particles may act as generators of the six primary imperfections. Conversely they may be generated in the imperfect crystal when it is appropriately bombarded, or if it contains radioactive constituents.

It is apparent from the comments made in describing the imperfections that they are not independent of one another. In fact the most valuable part of the viewpoint presented here probably is the observation that the different types of imperfection can interact both with imperfections of the same and different kind to alter characteristics and to generate other imperfections. Several examples may be given to illustrate this. (*a*) Phonons produced at elevated temperatures may interact to form lattice defects, such as vacancies, which condense to form dislocations when the crystal is cooled. (*b*) Similarly, experiments with the alkali halides show that rather intricate interrelations are possible. Light quanta may be absorbed in the crystal to generate excitons. These may in turn interact with dislocations to produce

vacant lattice sites, free electrons and holes. The vacant sites may capture the free electrons and holes to produce centers which render the crystal absorbing in regions of the spectrum, such as the visible, in which it was previously transparent. (*c*) Vacant lattice sites, present at thermal equilibrium in an alloy in which there is a chemical concentration gradient, may be swept out of a volume of the crystal as a result of the action of the chemical gradient. Dislocations present may act to regenerate the equilibrium concentration. In so doing the dislocation pattern of the lattice is altered and a process akin to plastic flow occurs (Kirkendall effect). Thus the diffusion process may engender dimensional changes in the specimen which arise from the shift of dislocations as well as from the redistribution of atoms. (*d*) Impurity atoms, which are attached to dislocations because of the favorable stress fields which surround them, have a tendency to concentrate near dislocations and thereby lower the energy of the crystal. On the other hand this type of condensation has the effect of pinning down the dislocation and increasing the stress required to induce plastic flow.

6. CONCLUSION

It is probably not an unwarranted exaggeration to say that the interesting properties of most solids are determined as much by imperfections in the sense employed in the previous section as by the bulk material. From one viewpoint, it can be said that the ideal solid plays its most important role in providing a matrix in which the imperfections exist and in determining the properties of the imperfections. For this reason, the development of a closely coordinated, and reliable picture of the nature of possible imperfections and the manner in which they are generated and interact with one another probably constitutes as important a contribution to the field as any development which has taken place thus far in its history, whether one is interested in its pure or applied aspects. There is good evidence that we now have at least a qualitative understanding of the principal types of imperfection. In fact the writer would go as far as to say that it is exceedingly unlikely that it will prove necessary to augment the list given in the preceding section in any substantial way, for the six primary imperfections described there seem to form a very closely related family, in a genetical sense. If other imperfections, which are general to the solid types occur, they would seem to be independent of this primary group.

It is evident that highly specialized imperfections may occur in materials, such as ferromagnetic or ferroelectric solids, which have rather specialized and individualistic properties. For this reason the study of such systems will always be a fruitful field for extension of research in solids. It seems safe to say, however, that the straightforward examination of the principal imperfections in typical solids will provide a very stimulating and profitable field of research for at least a decade.

SCIENCE TODAY AND YESTERDAY

BY

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I have been asked to summarize the papers of this symposium. Now this is a very difficult task because it was impossible for me to have any opportunity to see the papers before what I was supposed to write had to be ready.

I am reminded of a situation which occurs occasionally in conducting classes in which a student wants to ask a question but doesn't know quite what the question is that he wishes to ask. Under these circumstances I encourage him to try, in the hope that I may find the question which he should have asked and then answer that. And so, in the present instance, if I were to follow strictly my assignment, and in the absence of knowledge as to what is contained in the papers which I am supposed to discuss and have not seen, I should myself have to write a series of corresponding papers representing the papers which I think should have been written and attempt to discuss these. This would not be very complimentary to the distinguished authors of the various articles, and so I am somewhat at a loss in this assignment. I have a suspicion that I am not the first who has been asked to undertake the assignment. In fact, I know I suggested some potential victims. I will not say who they were, since I have no desire to increase the number of my enemies. However, all of the aforesaid potential victims refused to take on the task, so in desperation, the Editorial Board has turned to me, conscious of the fact that avenues of escape are not so readily available to me as to the others; and if I protest as to the nature of the assignment, I am met with the request, or command, "Well, *you write something*."

In the light of the above situation, I can do naught but meditate. And as I meditate, I try to form a picture of what kind of a symposium this would have been if it had been held 300 years ago and how it would have compared with symposia in other fields of learning. A symposium on literature held 300 years ago would have the basic classics of all time to work on, it would have Shakespeare, it would have Horace, it would have Virgil. Yes, I believe that while the symposium on literature would cover rather different material today than it would have covered 300 years ago, the plane of sophistication would not be very greatly different. A similar remark might be made about a symposium on art—on sculpture and on painting (if we could only keep the modernists quiet). Even in music, while the wealth of literature would be much greater today than 300 years ago, at any rate if we should change

the 300 to 200 years, we should find basic principles of form and harmony in the older symposium on a level comparable with that of modern times. In science, however, what should we find? I think we should see a demonstration of a few phenomena concerned with the attraction of small bodies to a piece of amber which had been rubbed on the coat. We should see a demonstration of the properties of lodestone in attracting iron and in seeking the north. These phenomena would stand as more or less isolated pieces of information with the reason for their existence hovering in the shadowy realm between theology and witchcraft. We should have a paper by Galileo showing a new device in the form of a telescope which claimed to establish the existence of satellites for Jupiter. And in rebuttal we should have a paper by one Francesco Sizzi, a Florentine astronomer and an eminent exponent of the leading science of the day, who would point out the errors in Galileo's device in maintaining that it is nonsense to increase the number of the heavenly bodies, and for the following reasons, as expressed in his words:

"There are seven windows in the head—two nostrils, two eyes, two ears, and a mouth; so in the heavens there are two favorable stars, two unpropitious, two luminaries, and Mercury alone undecided and indifferent. From which and many other similar phenomena of nature, such as the seven metals, etc., which it were tedious to enumerate, we gather that the number of planets is necessarily seven.

"Moreover, the satellites are invisible to the naked eye, and therefore can have no influence on the earth, and therefore are useless, and therefore do not exist.

"Besides, the Jews and other ancient nations as well as modern Europeans have adopted the division of the week into seven days and have named them from the seven planets; now, if we increase the number of planets this whole system falls to the ground."

And then, if the symposium had been held 50 years or so later, it would have had the great discoveries of Galileo and Newton for material, discoveries so potent in their application to nature that we would find the audience at that symposium enthusiastic in the belief that they were beginning to understand nature. They certainly were beginning to understand in the sense of learning how an important realm of nature works. Possibly, the philosophers of that epoch would not have ventured to replace the word "how" by "why" and imagine that they were seeing a satisfying reason to account for why things were as they were. If there was a reason at all it was probably regarded as to be found in the decrees of the Almighty along the line of one philosopher who, seeking to understand the conservation of momentum, maintained that momentum was created by God. It was therefore perfect and indestructible and for this reason $\Sigma mv = \Sigma m'v'$.

But as time progressed, the principles of Newtonian mechanics

assumed such an important role that the fundamentals contained in them tended to masquerade as *natural* truths which appealed to that ill-defined concept, the glory of the practical man, the possession in some degree of all of us and the refuge of the fools of philosophy—common sense. This ogre, common sense, or horse sense—the kind of sense that a horse has—has been responsible for much philosophic unhappiness in the years that have passed.

The true philosopher and student of science seeks in nature *order* rather than *reason*. He is as one who examines an oriental rug and ferrets out certain principles of design. This is all that he needs in order to have the sense of what we call "understanding" the rug. Moreover, if he sees another rug, he is frequently fortunate in recognizing similar principles and this new rug is brought into the realm of those things which satisfy him. If then he should come upon a third rug in which the designs are drastically different from the others, he is not perturbed. He again seeks order in this new design and is content when order is established. However, common sense is apt to stand by and whisper many disturbing thoughts into his ear. After he had understood the first rug, common sense urged him to believe that he had done more than discover order, that he had discovered reason. I fear that if he should have asked common sense what these reasons were, that autocrat would be driven to realms of reason which even he would not like to admit. He would be driven into the mind of the maker of the rug who, in this matter, was a little god in creating these principles of design which were probably fashioned as symbols of the experiences which he encountered in his life and beliefs. Common sense, however, would probably avoid this kind of an explanation and would seek to drill into his listener the idea that the principles of form which the latter had discovered were really natural. In this sense, natural comes to mean something which was found to be applicable over a wide range—over a large number of rugs. The principle is akin to what is found in advertising, where, if you find John Smith's soap depicted in a sufficiently large number of places, you will be apt to conclude that it is a very fundamental kind of soap. In a less dignified form it is akin to the principle that if you tell a lie sufficiently frequently, everybody will believe it.

There would perhaps be not much harm in accepting the urges of common sense to grow reasons out of forms in the study of the first rug, were it not that these reasons might clash violently with the form which evolved from a study of the third rug. If we had enough rugs of the third kind, common sense would have to invent another set of reasons or, in more ambitious vein, would seek to invent generalized reasons of which the different rugs so far encountered represented special cases. In such acts, however, common sense is continually a thing born of the experiences of the immediate past and having estab-

lished itself at least temporarily on this basis, seeks oft to restrain the future.

And so the great realm of Newtonian mechanics gave birth, fathered by common sense, to a set of reasons, and everything new was strained as far as possible to fit with these reasons. There was much encouragement born of success of the procedure. The same reasons which had won birth in astronomy seemed to be happy in other new discoveries, the laws of operation of mechanical devices, the laws of acoustics, and in general the laws of wave motion in matter. However, optics stood to some extent apart. Then came the discoveries of Faraday and his contemporaries, and a powerful moulding by Maxwell of these discoveries into a consistent mathematical form. At this stage, common sense became perturbed. It was annoyed by the description of order in the happenings unaccompanied by reason born of the old experiences. When a thing here moved as a consequence of the motion of something else there, it demanded a medium in which its principles could be dissolved and provide continual comfort to the mental philosopher whose ships of thought sailed in that medium.

And so the mathematicians strained their efforts to provide pictures appropriate to a medium. Alas, the facts resisted the reasons and the kind of medium which was necessary was one that was so fluid, as common sense understands fluidity, that the planets can flow through it without the slightest resistance to their motion and yet so solid, as common sense viewed solidity, that it was more solid than steel. The mathematicians were able to define the properties of this medium with great precision but the medium was unlike any other medium which physics had encountered and common sense was much offended by it and has continued to be offended. However, for want of something better, common sense continued to drag its unsavory offspring, the ether, along with it wherever it went and the offspring proceeded to make trouble in every new domain which it encountered, and at last even common sense had to disown it and retire to a cantankerous seclusion in which it could boast of its achievements in its pleasurable companionships of the past and turn up its nose at the discoveries of the present and of the future, while the physicist engaged on these discoveries, having learned their lesson of the bad companionship of common sense, went ahead shamelessly without him and proceeded to concentrate upon forms and order rather than upon reasons.

And so there arose that abstract formulation of mathematical principles which we call the Quantum Theory, a set of principles so divorced from the domain of the common sense of the past as to have practically no contact with it and yet so powerful in their application as to comprehend in consistent form the whole realm of atomic structure and all that goes with it. The quantum theory has grown so fast that common sense, which in the past had been a reasonable collaborator

during such small changes of government as had occurred, was now utterly unable to keep pace and was not encouraged to keep pace because the working physicist expressed no need for his services.

It must not be thought, however, that the new was something inconsistent with the old, for the new includes the old but in a different guise. Indeed, as time progresses, it is not unthinkable that we may invite common sense in once more, in a chastened frame, it is true, and ask him to reformulate himself and dress in new raiment to conform to the principles of modern thought, and then seek to understand his earlier domains of activity in terms of the principles of the new common sense of the new domain. Indeed, there is no inconsistency between the old and the new. The new certainly harmonizes the old with itself, although the old cannot perform a similar feat. In harmonizing the old with itself, however, the new has not done so in terms of any principles of common sense. Indeed, it is frightened of common sense, but the possibility is always open for anyone to create a new common sense if he so wishes.

In the old days, though science was young, there was, nevertheless, much information in the world in the form of experience. Ships had sailed the seas for ages. Great monuments of architectural distinction had been erected thousands of years ago without a knowledge of science, and yet today no one would think of building a second floor garage without a discussion of scientific principles and without calculations based on such principles, principles which would have been known to nobody even three or four hundred years ago. The procedures available at such times were largely empirical, founded in large measure upon trial and error. Such general methods of procedure as were distilled out of empiricism could not be expected to have that unique formal simplicity and consistency which physicists demand of a theory in most fields of their interests. An example of this kind of thing, with a modicum of empiricism in it, is the expression by Kepler of his three laws of planetary motion, which, in their empirical form, served as a guide to the understanding of much that happened in the motions of the heavenly bodies. In his discovery of the law of gravitation, as exemplified in the law of inverse squares, Newton reduced these apparently independent empirical laws of Kepler to dependency in terms of the single postulate of the aforesaid law of gravitation. This is what the physicist would like to do for all those complex manifestations of phenomena which, in the past and to some extent in the present, are governed, as far as our knowledge is concerned, by empirical laws. Until the physicist has succeeded in his task, empiricism will have to remain the dominant tool of those who would make progress in the sciences concerned. However, what we call the fundamental laws of nature—the laws which we like to envisage as the simplest set of principles which comprise in their special cases all of the manifestations of

nature—these laws, insofar as we know them, are gradually eating into the empirical realm and reducing more and more of the phenomena of matter to a common realm of understanding.

In this connection, there is always before us a serious obstacle in the shape of complexity as distinct from perplexity. I may take as an illustration a study of the vibrations which I set up in a chair when I hit it with a hammer. The old classical laws of physics are sufficient for my illustration. I understand the equations of elasticity and of acoustical dynamics which I believe to be at the basis of the solution to my problem. I can formulate the problem because I know all of the boundary conditions necessary to make the solution of the equations unique, and yet I surmize that nowhere shall I find a mathematician of sufficient knowledge and ability to be able to work this problem out. The problem presents me with a situation of no *perplexity* but one of terrifying *complexity;* and yet, it might turn out that there were properties of the vibrations of my chair which were highly significant to my interests. These are really properties, not only of the fundamental laws, but of the special case to which I have applied those fundamental laws. Sometimes the things which are of interest in solutions of our problem are 90 per cent the consequences of the fundamental laws and only 10 per cent the consequences of the special case to which they are applied. In many cases the reverse is true and the very complexities which make the situation of interest in the practical sense are the things which prevent the mathematician from solving the problem, and in such cases empiricism must continue to reign until it is defeated by the invention of more powerful mathematical processes.

As a rule the physicist tries to simplify his problem to the end of securing two features, a problem which he can solve and yet one of sufficient generality to be of practical use. Unfortunately, when the things which are of interest are dependent on the complexities for their existence, the story of the fundamental physicist is apt to have little bearing on the matter and to be viewed with skepticism by the practical man who, on the basis of his wide if somewhat illogical set of principles, is able to accomplish what he desires with his complicated devices.

In discussing such matters as the foregoing, I am apt to cite the case of an old violinist, highly skilled in his art, but devoid of scientific knowledge. There comes to him a young physicist who says: "My friend, I have been watching you play that instrument and I am going to tell you how to play it better, for I am a student of acoustics and know all about the laws of sound." "Very well," says the old violinist, "here is the violin—play it." "Oh no," says the young physicist, "I would not wish to use that instrument at all. It is, indeed, a very stupid instrument, with no scientific background. It is strung with a cat's inside and played with a horse's tail. It has a form dictated by no scientific principles and the only information I have been able to find

with regard to it is to the effect that the form had something to do with the supposed figure of the Virgin Mary. I would like to study a very simple case first." And so our young physicist suspends a simple stretched string between two fixed points in space and he discusses all the various modes of vibration. He discusses how the frequency of vibration determines the pitch, how the overtones determine the quality, and so forth. The old violinist, much impressed but much bewildered, says: "All right, here is the bow. Now play it." When the bow is drawn across the string, the old violinist hears nothing, for we all know that a string so mounted would emit practically no sound at all. The old violinist complains that he cannot hear anything, but the young physicist feels that it is very unreasonable of him to insist upon what he deems the relatively minor matter of hearing something and proceeds to argue that it is much better to understand what you do not hear than to hear what you do not understand. But the old violinist is sad about this matter and goes away a little comforted by the fact that although he may not know what he is doing, he knows how to do it.

And so, on looking over the titles of the various papers which have been presented in this symposium, I see a multitude of fields of learning which, insofar as anything was known of them in the remote past, must have stood in that past largely as disconnected fields of knowledge. Even today, much that is of interest in the application of these fields of learning over the realm of practical affairs must rely on empiricism. Perhaps the mathematician is the purest of all in being free from the stigma of the rule of thumb procedure. The physicist likes to think himself well on the way to pureness of thought in all realms. The chemist has gone far, since the days of alchemy, and even the aims of the alchemist in the transmutation of the elements have been rendered respectable in the hands of the physicist and the chemist. As we come to the applied sciences and to the medical and biological sciences, we still live to some extent and in varying degrees in the realm of empiricism. But fundamental methods of approach, as, for example, in the theory of the solid state, are rapidly gravitating from a realm where the necessities of simplification preclude practical application and we have strong hopes that before long fundamental matters of such abstractness that no man of science of 50 years ago could have regarded them as anything but fantastic mental ramblings of madmen will play a vital role in determining methods for making machinery strong, for creating alloys with practical properties of a usefulness which we do not enjoy today, and of improving man's control over matter in a variety of ways.

And so, while we must, I think, regard even the purest and most fundamental laws of nature as ultimately empirical in kind, with horse sense left to the horses, it is our hope that some day this empiricism in its simplicity will contain in practical form the old empiricism with its complexity.

THE FRANKLIN INSTITUTE

MINUTES OF THE STATED MEETING

December 20, 1950

The December stated meeting of The Franklin Institute was held in the Lecture Hall on Wednesday evening, November 20, 1950, with approximately 240 persons attending.

The meeting was called to order at 8:30 by the President who reported that the minutes of the stated meeting for October were printed in full in the November issue of the JOURNAL, and that the minutes of the stated meeting for November are printed in the December issue. As there were no corrections or additions, the minutes were approved as printed.

In keeping with Article IV, Section 5 of the By-Laws, the Secretary announced that nominations for the Board of Managers were made in writing, and that the nominations were signed by at least two members who certified that the candidates would serve if elected. The following names of candidates were read:

Morton Gibbons-Neff	Charles S. Redding
Hiram S. Lukens	S. Wyman Rolph
George Wharton Pepper	John Russell, Jr.
M. M. Price	Clarence Tolan, Jr.

The President called for nominations from the floor and, there being none, the nominations were closed.

The following elections to membership have been recorded for November:

Active	36
Associate	39
Student	19

The total Institute membership as of November 30 was 5972.

The Secretary presented a list of those who will receive Silver Cards at the end of 1950 in recognition of the fact that they have been members continuously for from 25 to 49 years. There were 198 people on the list and geographically they live from California to Massachusetts and from Maine to Tennessee. The Board of Managers has requested that this list be included in the Minutes of this Meeting.

It was announced by the Secretary that the annual Planetarium show, "Star of Bethlehem" will be given throughout the month of December; and that the 1950 series of the James Mapes Dodge Christmas Week Lectures for Young People will be given on December 28 and 29. Dr. H. R. Kingston of the University of Western Ontario will present "Touring the Universe" on these dates.

The President welcomed the officers and members of the Philadelphia Society for Promoting Agriculture to their eleventh joint meeting with The Franklin Institute. Mr. J. Gordon Fetterman, President of the Society, was introduced and took the chair. At this time Mr. Fetterman introduced the speaker of the evening, Dr. Selman A. Waksman, Professor of Microbiology at Rutgers University and Microbiologist at the New Jersey Agricultural Experimental Station. Mr. Fetterman presented the Society's annual achievement award to Dr. Waksman.

Dr. Waksman, the co-discoverer of streptomycin, declared in the course of his talk that the present era will be known to history not as the atomic age but the antibiotic age. He held out the hope that some day the body may be made immune to infectious disease by means of antibiotics, and feels that we are far from reaching the limit in the development of these antibiotics.

A number of questions were asked by the audience, at the conclusion of which Mr. Fetterman adjourned the meeting by calling for a vote of thanks to Dr. Waksman.

HENRY B. ALLEN
Secretary

List of Silver Card members presented at the Stated Meeting:

1901
James M. Caird
Gano Dunn
Ralph D. Mershon
W. E. Moore

1902
Kern Dodge
John P. B. Sinkler

1903
Charles H. Howson

1904
Frank S. Busser
Elliott Curtiss
C. Mahlon Kline
George Woodward

1905
George R. Hall

1906
John L. Cox
Francis J. Stokes

1907
Darthela Clark
Frank Shaw Clark

1908
Herbert Berliner
George W. Borton
W. M. C. Kimber
J. George Klemm, Jr.
John B. Rumbough

1909
Theobald F. Clark
Walton Clark, Jr.
J. B. Klumpp
James McGowan, Jr.
George Missimer, Jr.
T. Edward Ross

1910
Richard P. Brown
Joseph S. Hepburn
Joseph W. Lippincott
Horace P. Liversidge
J. M. Weiss

1911
Seth B. Capp
E. M. Chance
W. H. Fulweiler
M. M. Price
Charles Penrose
Frederic Rosengarten

1912
James Barnes
John Hampton Barnes
Morris Llewellyn Cooke
Edwin Elliot
J. Logan Fitts
Benjamin Franklin
Herbert E. Ives
Walter Palmer
Howard S. Worrell

1913
Edward Bartow
George L. Coppage
Irenee duPont
Howard N. Eavenson
S. B. Eckert
Charles Engelhard
Ralph E. Flanders
N. E. Funk
Edwin H. Hammer
J. Kearsley M. Harrison
Lionel F. Levy
E. Mallinckrodt, Jr.
Frank M. Masters
Franklin P. McConnell
William Maul Measey
George A. Pierce
W. F. Wells
W. Chattin Wetherill
D. Robert Yarnall

1914
Russell L. Brinton
George S. Crampton
Ernest L. Huff
K. G. Mackenzie
Marshall S. Morgan
J. Edward Patterson
George Wharton Pepper

1915
Raymond Foss Bacon
C. E. Bennett
Thomas D. Cope
John C. Cornelius, Jr.
Justice C. Cornelius
H. Jermain Creighton
Thomas W. Elkinton
F. Lynwood Garrison
Richard Howson
S. Leonard Kent, Jr.
E. F. Kingsbury
W. Wallace McKaig
Walter F. Rittman

1916
Henry B. Allen
James G. Detwiler
Zay Jeffries
Richard C. McCall
Thorsten Y. Olsen
Frank H. Sauer
B. E. Shackelford
H. B. Spencer
Arthur Synnestvedt
James G. Vail
Leo Wallerstein
Charles N. Weyl

1917
A. D. Chambers
Francis J. Chesterman
Walter S. Crowell
P. T. Dashiell
William J. Fitzmaurice, Jr.
John D. Gill
Rolfe E. Glover, Jr.
Harold Goodwin, Jr.
Arthur W. Lowe
Frank S. MacGregor
Edward E. Marbaker
Francis F. Milne, Jr.
C. H. Quinn
Sylvan D. Rolle
Robert L. Wood
Henry Woodhouse

1918
Charles H. Colvin
Fred H. Colvin
Charles H. Masland, 2nd
Walter O. Snelling

1919
Charles E. Brinley
Henry Colvin, 2nd
E. A. Eckhardt
Edwin D. A. Frank
George W. Furness
Frank H. Griffin
Hiram S. Lukens

H. Conrad Meyer
J. Howard Pew
Edmund G. Robinson
L. K. Sillcox
W. Leigh Smith
William Tiddy
Lucien Yeomans

1920
Robert Cameron Colwell
Howard W. Elkinton
Francis W. Hartzel
Chester Lichtenberg
Haviland H. Platt
Carl D. Pratt
Frank L. Wright
Winthrop R. Wright

1921
Roland L. Andreau
Leonard T. Beale
J. Ed. Brewer
Frederic Palmer, Jr.
Frank H. Rogers
Howard Stoertz
James Stokley
Haakon Styri
Edward R. Weidlein
S. Weinberg
J. Lester Woodbridge

1922
J. L. Crenshaw
C. Douglas Galloway
Joseph F. Greene
L. H. Kinnard
L. W. McKeehan

1923
C. S. Chrisman
William Dubilier
Henry Clay Gibson
John Tracy Lay
Howard S. Levy
William C. Melcher, Jr.
John F. Metten
Lewis F. Moody
Richard H. Ranger
Jessie A. Rodman
Edwin G. Sagebeer
Coleman Sellers, 3rd
H. Birchard Taylor
Francis B. Vogdes
Joseph J. Vogdes

1924
Peter Abrams
H. Carl Albrecht
Clement Starr Brinton
Robert Craig
Karl K. Darrow
Lee Davidheiser
William G. Ellis
T. R. Harrison
Valentine Hiergesell
Karl F. Oerlein
Edward B. Patterson
Harold Pender
Nicholas G. Roosevelt
Alfred O. Tate
Walter C. Wagner
James Lloyd Weatherwax
Alexander Wilson, 3rd
William Zimmermann

1925
Joseph S. Bennett 3rd
Jack G. Binswanger
William L. Brown, 3rd
Marion Eppley
John Graham Foley
J. V. Giesler
C. R. Kraus
J. Kenneth W. Macalpine
William Stanton Monroe
W. F. G. Swann
J. R. Wyatt

The following are Gold Card members, having belonged continuously for 50 years or more. The dates are years of election to membership.

Arthur W. Howe '84
Alexander Sellers '84
William R. Armstrong '85
William Henry Bower '85
G. H. Clamer '91
Pierre S. duPont '92
Walter T. Lee '92
Norman Mellor '92
Daniel Eppelsheimer '94
J. H. Granbery '95
Edward Woolman '95
Alan Wood, III '96
Morris E. Leeds '97
T. C. McBride '97
D. S. Jacobus '99
John J. McVey '99
E. A. Muller '99
Reginald Norman '99
C. C. Tutwiler '99
Frederic A. Delano '00

MUSEUM

TEMPERATURE MEASUREMENTS BY ELECTRICITY

The first approximate thermometer was probably invented by Giambattista della Porta, although it is generally attributed to Galileo, who used one about 1597. This was a thermometer employing air confined in a bulb connected to a vertical tube in which moved an index of colored alcohol. The air was practically at the pressure of one atmosphere. By 1650 the Accademia del Cimento used a sealed type of tube which permitted measurements of higher temperatures and made the readings independent of barometric pressure. These early thermometers can hardly be said to measure temperature. They were rather indicators, for the fixed points for calibration were mostly too vague, such as the temperature at which butter melted or the temperature of a deep cellar. Fahrenheit, a Dantzig glass blower, popularized mercury thermometers by constructing them with scales in good agreement among themselves.

One usually associates accurate temperatures with laboratory experiments but at some stage of their making practically all industrial products pass through one or more processes in which temperature is an important factor. Clearly the instruments of today must have improved tremendously over those we have mentioned above, for choice of method and instrument to keep the temperature within set limits may have a considerable bearing on product quality and cost, and on the continuity of production. In developing methods and instruments to hold an ever widening variety of manufacturing processes within increasingly closer temperature limits, industry has followed the lead of science. By insisting that the sound principles underlying laboratory measurements be applied to instruments adapted to the rough conditions of plant use, it has advanced from the old "spit and sizzle" method to modern instruments of high accuracy to fulfill many and varied needs. These later instruments are far advanced from the simple mercury thermometers with which we are all familiar, and employ the principle of thermoelectricity.

Thermoelectricity may be said to have had its origin in 1821 when Seebeck discovered that an electric current flows continuously in a closed circuit of two dissimilar metals when their junctions are at different temperatures. This is the thermocouple. Then, resistance thermometers were suggested by Siemens in 1871, and were quickly adopted for industrial purposes. If a resistance coil be constructed and its resistance measured at certain known temperatures, then the resistance at other temperatures can be used to measure those temperatures. This, in principle, is the resistance thermometer.

The firm of Leeds and Northrup, recognized specialists in the field of electrical measuring instruments, has prepared an exhibit for the Museum which demonstrates some of the uses of their instruments in industry. The first is the "Thermohm," an electrical resistance thermometer of high precision. This instrument is used widely in air conditioning, medical research, candy making, freezing and preserving food, and in nickel, silver, and copper plating. The illustration chosen by the makers shows a Thermohm inserted in a stalk of bananas to detect the temperature of the ripening fruit.

The second specimen is a Thermocouple, a simple temperature detecting device, which is also widely used in industry for "low" temperatures (that is, up to 1000° F.). This device produces a voltage when exposed to heat. This voltage is readily converted to a temperature reading. Special types of thermocouple are dipped into retorts of molten aluminum to tell when the temperature is right for pouring the hot metal into molds. More commonly, thermocouples are permanently mounted in furnaces, baths, and other production units for continuous measurements.

When operating temperatures are so high that thermocouples would burn out or when hot work is moving so that a thermocouple cannot touch it, other means of temperature measurement have had to be devised. One such device is the "Rayotube," which enables the operator to detect temperatures from a safe distance by simply "looking" at red- or white-hot objects. Formerly, steel operatives had to judge critical moments solely by the appearance of the melt. With experience one could probably estimate temperatures visually to within

100° F. This is not precise enough for many modern steel processes, so that the Rayotube, an optical pyrometer which measures radiation, has been developed to sight upon the hot object from a fixed location, and to report the temperature to a recording instrument. This is the third illustration of the exhibit and shows the use of the instrument in the drawing of steel rods into wire. The bars of steel must be kept constantly at exactly the right working temperature.

The fourth example of electrical measuring devices is another form of optical pyrometer, and is an accurate instrument for quickly measuring the temperature of a red-hot object at various stages of production. It is shown in use taking the temperature of red hot steel coming from the furnace for forging. This is a typical case where very high temperatures have to be measured on the spot in a hurry.

In keeping with the spirit of the Museum, these excellent exhibits of the Leeds and Northrup Company can all be operated by the visitor.

JOURNAL OF THE FRANKLIN INSTITUTE

The following papers will appear in the JOURNAL within the next few months:

MOON, PARRY AND DOMINA EBERLE SPENCER: Simplified Interflection Calculations.
MALKIN, I.: Stress Analysis of a Hemispherical Pressure Vessel Head Under Concentric Line Loads.
EISENBUD, LEONARD: On the Theory of Angular Correlation.
SILBERSTEIN, LUDWIG: Paucity of Quanta Rendering a Silver Halide Grain Developable.
GROSS, ERIC T. B. AND LEONARD RABINS: Transient Analysis of Three-Phase Power Systems.
ORDUNG, PHILIP F. AND HERBERT L. KRAUSS: Frequency-Coordinate Vector Diagram.
DRENICK, R.: The Perturbation Calculus in Missile Ballistics.
STAUDER, W. V. AND A. H. WEBER: Electron Diffraction Studies of Etched Gold Leaf Films.
LEE, FREDERICK B.: Our New Aerial Highways.

MEMBERSHIP

ACTIVE MEMBERS ELECTED AT THE MEETING OF THE BOARD OF MANAGERS, DECEMBER 20, 1950

ACTIVE FAMILY

Samuel L. Fahnestock	Meyer A. M. Mathiasen	Edward W. Schoolfield
Joseph W. Hancock	Ernest D. Menold	Ashton T. Scott
	Douglas A. Schoerke	

ACTIVE

Matthew A. Cavanaugh	William E. Jewell, Jr.	Claude C. Peavy
Jacob H. Finkelstein	William Kegelman	William J. Schar
Michael Gargaro	Jurian N. Leggett	Arthur W. Shaw
Simon E. Gluck	L. R. Lewis	Harry E. Wagenseller
R. M. Goodman	The Rev. John C. McGlade	Meade E. White
Elmer R. Gross, M.D.	Otto Paul Meyer, Jr.	R. F. Whitelegg
Bernard Haimowitz	George Mitchell	Robert Wooler

ACTIVE NON-RESIDENT

Charles W. Delp, Jr.	Ellsworth F. Seaman	Earl B. Strowger

NECROLOGY

James L. Crenshaw '22	Edward Kelley '48	Paul J. Startzman '46
Harry A. Fink '42	Thomas M. Lightfoot '89	Herbert S. Welsh '37
C. Walker Jones '43	W. D. Loughlin '44	C. B. White '38

LIBRARY

The Committee on Library desires to add to the collections any technical works that members would wish to contribute. Contributions will be gratefully acknowledged and placed in the library. Duplicates received will be transferred to other libraries as gifts of the donor.

Photostat Service. Photostat prints of any material in the collections can be supplied on request. The average cost for a print 9 × 14 inches is thirty-five cents.

The Library and reading room are open on Mondays, Tuesdays, Fridays and Saturdays from 9 A.M. until 5 P.M.; Wednesdays and Thursdays from 2 P.M. until 10 P.M.

RECENT ADDITIONS

ASTRONOMY

LE MAÎTRE, CANON GEORGES. The Primeval Atom. 1950.

AVIATION

PORT OF NEW YORK AUTHORITY. Air Traffic Forecast, 1950-1980. 1950.

BIOGRAPHY

VAN DOREN, CARL. Jane Mecom; the Favorite Sister of Benjamin Franklin. 1950.

BIOLOGICAL CHEMISTRY

BONNER, JAMES. Plant Biochemistry. 1950.

Cold Spring Harbor Symposia on Quantitative Biology. Vol. 14. 1950.

CHEMISTRY AND CHEMICAL TECHNOLOGY

BOEKENOOGEN, H. A. De Scheikunde der Oliën en Vetten. 1948.

BROWN, GEORGE GRANGER. Unit Operations. 1950.

FUSON, REYNOLD C. Advanced Organic Chemistry. 1950.

GILARD, PAUL. Traité de Physico-chimie des Silicates. 1947.

GNAMM, HELLMUT. Die Lösungsmittel und Weichmachungsmittel. 1950.

HAHN, OTTO. New Atoms, Progress and Some Memoires. 1950.

HILDEBRAND, JOEL HENRY AND SCOTT, ROBERT LANE. The Solubility of Electrolytes. Edition 3. 1950.

HOLLEMAN, ARNOLD FREDERIK. Einfache Versuche auf dem Gebiet der Organischen Chemie. 1907.

HULTZSCH, K. Chemie der Phenolharze. 1950.

INDUSTRIAL AND ENGINEERING CHEMISTRY. Modern Chemical Processes. 1950.

KERN, DONALD Q. Process Heat Transfer. 1950.

KOFLER, LUDWIG AND KOFLER, ADELHEID. Mikro-methoden zur Kennzeichnung Organischer Stoffe und Stoffgemische. 1948.

KRÖNIG, WALTER. Die Katalytische Druckhydrierung von Kohlen Teeren und Mineralölen. 1950.

LAIDLER, KEITH J. Chemical Kinetics. 1950.

LE BEAU, P., ED. Les Hautes Temperatures et Leurs Utilisations en Chimie. 1950.

PFEIFFER, J. P., ED. The Properties of Asphaltic Bitumen. 1950.

REMINGTON, JOHN STEWART. Drying Oils, Thinners and Varnishes. 1950.

RIES, C. Das Selen. 1918.

ROBINSON, CLARK SHROVE AND GILLILAND, EDWIN RICHARD. Elements of Fractional Distillation. Edition 4. 1950.

SANDELL, ERNEST BIRGER. Colorimetric Determination of Traces of Metals. Edition 2 1950.

SCHMID, E. AND BOAS, W. Plasticity of Crystals, with Special Reference to Metals. 1950.

STAUDINGER, HERMANN. Anleitung zur Organischen Qualitativen Analyse. 1923.

ELECTRICITY AND ELECTRICAL ENGINEERING

BAXTER, H. W. Electric Fuses. 1950.
BLOOMQUIST, W. C. AND OTHERS. Capacitors for Industry. 1950.
FRÉROT, CHARLES. La Technique du Chauffage Electrique. 1950.
POHL, ROBERT WICHARD. Einführung in die Elektrizitäts Lehre. Edition 4. 1935.
SCOWEN, F. An Introduction to the Theory and Design of Electric Wave Filters. Edition 2. 1950.
YOUNG, H. P. Electric Power System Control. Edition 3. 1950.

ELECTRONICS

MARTIN, THOMAS L., JR. Ultrahigh Frequency Engineering. 1950.
TREWMAN, HARRY FREDERICK. Electronics in the Factory. 1949.

ENGINEERING

MACINTIRE, HORACE JAMES AND HUTCHINSON, F. W. Refrigeration Engineering. Edition 2. 1950.
STANIAR, WILLIAM, ED. Plant Engineering Handbook. 1950.
SUTHERLAND, CLARENCE HALE AND BOWMAN, HARRY LAKE. Structural Theory. Edition 4. 1950.

FOOD

HOWARD, A. J. Canning Technology. 1949.

GENERAL

BLACK, MAX ED. Philosophical Analysis. 1950.
PARSONS, JOHN E. The Peacemaker and its Rivals; an Account of the Single Action Colt. 1950.

GEOLOGY

KUENEN, H. Marine Geology. 1950.

INDUSTRIAL MANAGEMENT

HEMPEL, EDWARD H., ED. Small Plant Management. 1950.

MANUFACTURE

LEWIS, L. M. AND LEE, MAX. Better Watchmaking . . . Faster. 1950.
SCKOTZ-HANSEN, KAJ. Glarmesterhandbogen. 1949.

MATHEMATICS

COURANT, RICHARD. Dirichlet's Principle; Conformal Mapping and Minimal Surfaces. 1950.
HOGBEN, LANCELOT. Chance and Choice by Cardpack and Chessboard. Volume 1. 1950.
HOBSON, E. W. The Theory of Functions of a Real Variable and the Theory of Fourier's Series. Volumes 1-2. Edition 3. 1950.
SMITH, GEOFFREY MOTT. Mathematical Puzzles for Beginners and Enthusiasts. 1946.
STEINHAUS, H. Mathematical Snapshots. 1950.

MECHANICAL ENGINEERING

BERGÈRE, J, Résistance et Encombrement des Engrenages. 1948.
HESSELMAN, JONAS. Teknik och Tanke. 1948.
JACORLEFF, D. Elements de la Théorie des Moteurs a Combustion Interne a Régime Rapide. 1949.
KAUFMANN, WALTER. Einführung in die Technische Mechanik. Vol. 1. 1949.
MAYR, F. Ortsfeste und Schiffsclie Selmotoren. Edition 2. 1948.
MESSERSMITH, CHARLES WILLIAM AND WARNER, CECIL FRANCIS. Mechanical Engineering Laboratory. 1950.

PHOTOGRAPHY

HOLM, E. Das Objectiv im Dienste der Photographie. 1902.
LAUBENHEIMER, KURT. Lehrbuch der Mikrophotographie. 1920.

PHYSICS

BANDOW, FRITZ. Lumineszenz. 1950.
BOLL, MARCEL. La Mécanique du Visible et de l'Invisible Mouvements, Mecanismes, Moteurs. 1949.
BROGLIE, LOUIS VICTOR DE. Mécanique Ondulatoire du Photon et Theorie Quantique des Champs. 1949.
BURRI, CONRAD. Das Polarisationsmikroskop. 1950.
GARNIER, RENÉ. Cours de Cinématique. Ed. 2. 1949.
GRANIER, JEAN. Les Phénomèmes Vibratoires. 1949.
HAMEL, GEORG. Theoretische Mechanik. 1949.
HOPKINS, H. H. Wave Theory of Aberrations. 1950.
JENKINS, FRANCIS A. AND WHITE, HARVEY E. Fundamentals of Optics. Edition 2. 1950.
LINFORD, A. Flow Measurements and Meters. 1949.
PECK, W. J. AND RICHMOND, A. J. Applied Thermodynamics Problems for Engineers. 1950.
PERISCO, ENRICO. Fundamentals of Quantum Mechanics. 1950.
PÖSCHL, THEODOR. Einführung in die Analytische Mechanik. 1949.
RAINICH, GEORGE YURI. Mathematics of Relativity. 1950.
TIMMER, JOHN DEZENDORF. Response of Physical Systems. 1950.

PLASTICS

SCHACK, WILLIAM, ED. A Manual of Plastics and Resins in Encyclopedia Form. 1950.

SCIENCE

BUSH, GEORGE P. AND HATTERY, LOWELL H., ED. Scientific Research. 1950.
FORBES, ROBERT J. Man the Maker. 1950.

STEAM ENGINEERING

MAK, A. Stoomturbines. 1948.

SUGAR

GILMORE, A. B. Porto Rico Sugar Manual Including Data on Santo Domingo Mills. 1950.

TEXTILES

HARTSUCH, BRUCE E. Introduction to the Textile Chemistry. 1950.

WOOD

BROWN, NELSON COURTLANDT. Forest Products. 1950.
NATIONAL LUMBER MANUFACTURERS ASSOCIATION. Forest Products Research Guide. Edition 4. 1950.

NOTES FROM THE BIOCHEMICAL RESEARCH FOUNDATION

NUCLEIC ACIDS AND CANCER RESEARCH

BY
ELLICE McDONALD AND WILLIAM A. MOSHER

Problems related to growth, both normal and abnormal, are at the center of many biological researches at the present time. Actually, this has been true for many years because modern scientific man has changed his broad objectives very little from those of his more primitive ancestors. This is because the desire for health and material things, physical and economic security, is still high in man's concern. In methods of research we also find some striking similarities over the centuries but important differences also exist. Because the scale of present biological-related research has grown to mammoth proportions, misconceptions frequently enter the picture: it is easy to let modern intensity of effort and fancy facilities overshadow rather ancient research philosophies.

Research methods may be classified in one of two broad divisions: fundamental or trial and error. It is rather hard to find many recent examples of trial and error research because a great deal has been learned down through the ages which permits the introduction of some fundamental aspects. Still a great share of biologically related research will include extensive testing programs based on isolated and frequently unconfirmed observations.

The value of the trial and error, or Edisonian, method of research should not be minimized, because it has led to important discoveries. The Edisonian method, based on some fundamental information, is widely used today, especially in those industries where the factors involved in a product or process are not clearly understood or where the theory is obscure. Man's impatience for progress tempts him to try things without thorough study.

The proponents of this method of research can cite long lists of results which have come from such an approach and these gains cannot be denied. But with the exception of some examples of great luck the successes have come from fields where the number of variables are limited or easily controlled and where relatively simple testing procedures are available. Take the important problem of insecticides for example. The investigator in this field can learn enough about the physiology of insects to apply the fundamental method but it is comparatively easy to try a variety of substances to see what types of chemical agents will kill insects. This method has been very successful and has made millions of dollars and has killed many billions of insects.

But can we apply the same technique to cancer? Here the variables are manifold and the reading of test results is not like counting dead flies. There are about 500,000 known chemical compounds, any one of which, *a priori*, might be selected for test. The trial and error method might eventually succeed, but the chances are almost infinite against an early solution. Through a study of cellular functions and chemistry we should, however, be able to find a rational basis for drug selection.

Confronted with the immensity of the problem we must find some manner of attack which will lead forward, eventually to the information on which a solution may be based.

The laboratories of the Biochemical Research Foundation were established about twenty years ago for the special purpose of attacking problems of growth and cancer by the application of fundamental research methods of all promising types. As a result, a group composed of biologists of various types, chemists, physicists, library workers, mechanics, and technical assistants with a great variety of specialties have cooperated in the advancement of this work. The specific nature of the investigations has, of course, changed from time to time as new and more promising leads have been opened up here and elsewhere, but always the goal has been basic understanding of biological processes, the defining of biological phenomena in the specific terms of chemistry and physics.

As we look back, we find that we, along with many other zealous scientists, have been enthusiastic about paths of research which eventually did not justify our enthusiasm. In all cases, however, the results have been valuable although the desired progress was not made; any basic scientific work, if done well and thoroughly, is of value, eventually perhaps of inestimable value. We have been recently led to an intense study of the nucleic acids, their chemistry and their role in biological processes. Perhaps we may be mistaken as to their importance but the leads are so attractive and the inter-relationships so compelling that we are confident of a great reward in vital information from their study. Let us consider briefly some of the facts which have compelled us to move in this direction as well as some of the important facts which have so far been forthcoming.

Any biological study sooner or later comes to rest on cellular behavior. Here we have the common denominator of growth. In the division of the cell we have the passing on of normal behavior to successive generations and the possible development of abnormalities in the daughter cells. If something goes wrong in the division process this error will be imposed on the resulting generations. Only one cell with a wrong heredity is necessary to start a profound abnormality in growth. Although it is attractive to blame a faulty cellular heredity for apparently spontaneous cancer, there seems little reason to consider

this disease inherited in the sense that the color of the hair or the length of the nose are inherited characteristics. What then might cause the occurrence of genetic alteration?

Some of these things we know. Radiation with x-rays in small doses will cause changes in the mode of growth of a variety of cells. Flowers can yield seeds which produce varieties quite different from their parents. Insects undergo genetic changes. We have reason to believe that energy-rich radiation of all types can lead to profound modification in genetic properties. After all, x-radiation can kill some cancerous tissues more readily than it kills normal tissues and x-radiation can cause cancer. The study of radiation on tissue has probably brought us to the most promising of the fundamental approaches in growth research.

Several years ago, while studying the biological effects of radiation, we observed that x-rays destroyed the ability of tissues rich in nucleic acid to absorb ultraviolet light strongly in the region of 2600 Å. Other forms of radiation showed a similar effect. Researchers in other laboratories learned that the effect of x-radiation on nucleic acid *in vitro* was to break the molecule into smaller pieces, to depolymerize the highly polymerized nucleic acid molecule. Surprising enough, the depolymerization continued for a short time after the radiation had been terminated. This looked to us like a chain process and we undertook to investigate the nature of the reaction. The results indicate clearly that a free-radical chain process is involved because we of the Biochemical Research Foundation were able to duplicate the effects of x-radiation with chemical agents such as hydrogen peroxide, vitamin C, and the like in the test tube. It is clear that radiation on tissue containing water and oxygen might start similar reaction changes. It is a simple matter to break up chemically induced chains and we soon found that chain breakers such as used in synthetic rubber preparation, thiourea, for example, would minimize the destructive *in vitro* effect of radiation on nucleic acids. When the same chemical was tried in mice, the mortality from x-radiation, and presumably from neutron bombardment as well, was greatly reduced. The importance of oxygen was demonstrated by showing that animals radiated while in an atmosphere low in oxygen showed greater resistance than those in a more normal, or higher concentration of oxygen. Plants and animals living in high altitudes are subjected to rather intense radiation, especially ultraviolet; the lower concentration of oxygen may be a factor moderating undesirable effects from this radiation. These studies were carried out originally with desoxyribosenucleic acid (DNA) but are being now confirmed as well using high polymeric ribosenucleic acid (RNA) which we have only recently been able to isolate.

The over-all action of radiation is now on something of a chemical

basis. Are the curative and the destructive effects of radiation due to this chemistry? We have some reason to suspect that this may be the case and work continues along these lines.

Because of the inter-relationship between DNA and the chromosomes of the cell nuclei, anything which affects the nature or the amount of DNA in the nuclei may have an effect upon cell division and cellular genetics. A study of the effects of restricted and normal diets on the production by azo dyes of tumors in experimental animals led us to the conclusion that variations in cell size, nuclear size, and amount of nucleic acid was also changing. The most startling change was the amount of nucleic acid per nuclei on diets which were free or very low with respect to protein. While the nucleic acid went up so did the alkaline phosphatase enzyme concentration; acid phosphatase concentration did not change appreciably at the same time. Some investigators, working with rather small numbers of cells, have been led to believe that the amount of DNA in a nucleus is a fixed quantity for a species. Although this is an attractive picture from genetic considerations, the variations we have observed are so clean cut and so suggestive for additional work that the older premise must be abandoned. In arriving at these conclusions observations have been made on many thousands of individual cells, and a new method of analysis which permits us to determine the absolute amount of DNA in a single cell nucleus has been developed.

How proteins fit into the nucleic acid picture is certainly not known but we may have the means now at our disposal for tying these two highly important groups of biologically active substances together.

We must never lose sight of the fact that the study of life must be a dynamic study. Although we are involved in strictly chemical work on nucleic acids, the usefulness and fate of these substances in life processes must always be before us. Dynamic biology involves chemical reactions *in vivo* and chemical reactions *in vivo* mean enzymes. Not only is the enzyme important in itself but, because of its specificity, may be readily detected and determined quantitatively in cells. Our full use of cytochemical techniques on enzymes related to the nucleic acids is bringing forth important information on these enzymes as well as on enzyme action in general. Certain of these enzymes show their greatest activity in the test tube at pH's appreciably different from those established for living cells. This apparent anomaly has been explained by assuming that considerable differences in pH exist in various parts of the cell or in different parts of cellular structures, a perfectly reasonable explanation which may still be valid. Recent work here, however, calls attention to the fact that the concentrations of substrates used in the usual test tube work are many, many times greater than the physiological concentrations. When substrate concentrations are reduced to approach the actual cellular values, the pH optimum approaches that

known to exist in cell fluids. This easy tendency to leave the cell and go to the test tube sometimes leads to wrong conclusions.

Exciting results with "cytotoxic" substances, radiometric chemicals which have more or less direct effects on chromosomes, have recently been published by workers in England. Tests on experimental animals indicate that a high degree of regression of tumors of certain types is possible. The relationship between nucleic acids and these agents is not yet clear. For some time now, we have been carrying out studies on slowly occurring changes in tissues as a result of cell poisons. This work will continue, directed at clarification of the biochemical effects of such agents.

It seems safe to say that the recognition of the importance of nucleic acid processes constitutes the most significant recent advance in the study of growth processes, which includes cell division in cancer.

Why did we wait until 1945 to initiate this large scale assault when the rudiments of nucleic acid chemistry had been known for about 25 years? We were not mentally or physically ready for the attack until that time; we had need of techniques and methods of study which had not yet been developed. As a matter of fact, every advance step at present requires the development of methods for following the changes under study. On the other hand, our earlier work, including that done for the Manhattan Project during the war, served as the preliminary training for the study now before us. Working as we are in basic cell functions and behaviors, every study offers vital training and information for each successive investigation.

The Biochemical Research Foundation will continue the application of fundamental experiments and fundamental thinking to the great problems of growth and cancer, with special emphasis on the nucleic acids and related systems and substances. Each week brings forth new knowledge, not all directly applicable to the treatment of disease but knowledge that brings with it the sure realization that success will come.

Franklin's Electrical Machine

In view of the recent study of the Chemical Society of Philadelphia[1] and because of its own inherent interest in authenticating one of The Franklin Institute's most treasured possessions, Franklin's electrical machine, it was thought that reproduction of the following would appeal to readers of the JOURNAL. As the letter is largely self-explanatory, no further comment seems necessary.

G. E. P.

To the Managers of the Franklin Institute
Gentlemen

In requesting your acceptance of the accompanying Electrical Machine, I beg you to estimate its importance, not from any intrinsic value in itself, but from its having belonged to the venerable Philanthropist & Sage, whose name designates the Institution over which you preside. It is believed to be the identical machine, with which he performed those Experiments that helped to immortalize him; and which are detailed in the Philosophical Transactions of the period in which they were made.

I have somewhere seen a statement, that Dr. Franklin's Electrical Machine was in the possession of General la Fayette, & graced an apartment at la Grange. It is highly probable that the Doctor may have constructed a variety of Machines in the course of his long continued devotion in the pursuits of Electricity; and that some of them have found their way to distant parts. The following statement, will however render it almost certain, that *this*, was his favorite Machine, & the longest preserved by its illustrious owner.

In the year 1792, a number of medical students of the University of Penn[a] associated to form a Chemical Society. Amongst them was the late Dr. W[m] Bache, my particular friend & fellow Graduate; who began his Medical pursuits, under the direction of the late Dr. Wistar, in the year which terminated the mortal career of his immortal Grandsire. Dr. Bache was the favorite Grandson of that Great Man, owing in part, to the congeniality of their pursuits; and the Machine in question, was a present to him, a short time before his death. It was highly esteemed by Dr. Bache, and was always regarded by him, as the one principally employed by Franklin. The estimation in which he was held by the Chemical Society, soon raised him to a considerable standing in it; & he kindly loaned, and subsequently presented to the Society, which he trusted would be permanent, this memorial of his Grandfather's affection. Dr. Woodhouse, Professor of Chemistry in the University, & then president of our Society, was permitted the use of this Machine, in the pursuit of his lectures; but whilst in his possession, the Society was broken up, and was never again organised. At the death of Dr. Woodhouse in 1809, I was appointed to succeed him in the Chemical department of the University, and purchased all his apparatus, amongst which I found the Machine I now transmit to you. I have had it in my possession nearly 17 years; and have concluded that I could not find a better, nor more permanent location for it, than in the Cabinet of an Institution so happily conducted as yours. The name your Institution bears, must incite to emulation & perseverance, its members; for it would be the extreme of incongruity, to have that name associated with indifference and neglect.

Wishing you Gentlemen, uninterrupted success in your great & praiseworthy pursuits; & hoping that the adage "Esto perpetua," may be applicable to your Institution, I beg leave to subscribe myself, with much respect,

Yr very obedient servt.
John Redman Coxe
Augt. 4th, 1826.

[1] See review of *Chymia*, Vol. 3. this issue of the JOURNAL. p. 202.

NOTES FROM THE NATIONAL BUREAU OF STANDARDS*

DIAPHRAGM-TYPE MICROMANOMETER WITH ELECTRONIC PICK-UP

A diaphragm-type micromanometer, utilizing an electronic pick-up, has been developed recently at the National Bureau of Standards to measure differential pressures in the micron region. Constructed for use with a mass spectrometer, the micromanometer gives rapid, direct readings of pressure on a microammeter scale that can be calibrated directly in units of pressure. It is relatively insensitive to temperature changes, will operate in any position, and permits measurements that are totally independent of the type of gas or vapor being measured.

The need for such an instrument arises from the inevitability of error in the usual method of measuring gases for use in a mass spectrometer. A small sample is measured in an ordinary U-tube manometer and passed into the reservoirs of the machine, where it expands to 1000 times its original volume. Its pressure is then assumed to be one one-thousandth of its original pressure, but this assumption fails to account for losses that occur through adsorption of the vapor by stop-cock grease and the walls of the system, and deviation from perfect gas laws.

It is desirable, therefore, to measure the pressure of the sample in the reservoirs after the losses have occurred. Manometers for the range from one thousandth of a millimeter to one tenth of a millimeter of mercury are usually liquid-level devices, such as McLeod gages, or depend on thermal effects, such as Pirani or thermocouple gages. McLeod gages are accurate, but the presence of mercury or oil vapor introduces difficulties into vacuum work; besides, these instruments are bulky and inconvenient to use. Pirani and thermocouple gages, while avoiding these difficulties, are inaccurate, and, unless special care is exercised, give only a rough indication of the vacuum.

The instrument developed at the Bureau consists of a pressure cell and an electronic micrometer, enclosed in a glass dome which can be evacuated or filled to any desired reference pressure. The pressure cell, the heart of the instrument, is composed of a very thin corrugated diaphragm sealed at the periphery to a slightly dished brass disk. This cell is connected to the gas sample so that change in pressure of the gas causes movement of the flexible diaphragm. Movement of the

* Communicated by the Director.

NOTE: Further technical details of the application of the micromanometer to the mass spectrometer will be given in a forthcoming article by V. H. Dibeler and F. Cordero in the *Journal of Research* of the National Bureau of Standards. Details of the design, operation and performance of the electronic equipment itself will be covered in a companion article by M. L. Greenough and W. E. Williams.

diaphragm in response to pressure variations is measured by a mutual-inductance micrometer placed over, but not in contact with, the diaphragm. Mechanical coupling errors are thus eliminated.

The micrometer was previously developed at the Bureau in connection with the design of indicating devices to measure clearances in journal bearings. (*NBS Technical News Bulletin* Vol. 31, p. 37 (April, 1947)). In principle, it makes use of the variation in mutual inductance between two concentric air-core coils which results when the distance of the coils from a nonmagnetic metal surface changes. When the metal is brought immediately adjacent to the end of the form supporting the coils, the mutual inductance is reduced to a minimum by what is effectively a "shielding" action of the metal. As the metal is moved away from the coils, the mutual inductance increases as a linear function of the separation.

In the micromanometer, the metal "shield" is the diaphragm of the pressure cell itself. Radio-frequency current is fed into a primary coil and induces a voltage in a secondary coil, mounted just above the diaphragm. The form supporting the coils is mounted rigidly with respect to the fixed portion (the brass disk) of the cell. Mutual inductance between coils is therefore a function of diaphragm expansion and hence is indicative of gas pressure.

This mutual inductance is compared to an adjustable reference value which is set in calibration for equality with zero differential in the cell. When pressure is applied, the balance is disturbed, and the resulting signal is proportional to gas pressure. This signal is amplified by suitable circuitry, is rectified, and finally appears as a d-c. current through the microammeter on the panel of the instrument.

Alignment of coil form and diaphragm is not critical since, as a result of the linear response, all parts of the useful area of the diaphragm are weighted uniformly.

Because of the linear relationship between pressure variation and electrical output, only two calibration points are required. In practice, the cell is first evacuated to the same pressure as that prevailing in the glass dome. Thus no differential pressure on the diaphragm exists, and the reference mutual inductance may be adjusted for zero reading on the meter scale. Slope, or scale-factor, adjustment is then made upon the introduction of an expanded gas sample of known pressure.

The manometer is capable of measuring pressures in the range of 1 to 100 microns with a sensitivity of about 0.1 micron on a 50 micron scale. Continuous use of the instrument for more than one year on one of the mass spectrometers at the National Bureau of Standards has shown that its sensitivity and zero point are remarkably constant. Frequent observations have disclosed variations in calibration of less than 1 micron over a 24-hr. period. A differential pressure of one atmosphere applied externally on the pressure cell has only a slight

hysteresis effect while pressures up to several tenths of a millimeter can be applied inside the pressure cell without harmful effects on the diaphragm.

APPARATUS FOR STUDYING TEMPERATURE-SENSING DEVICES IN JET ENGINES

Efficient operation and adequate protection of the power plant in jet engines require very rapid reduction in the temperature of the gas stream whenever this temperature exceeds a limiting safe value. The rates of response of whatever temperature-sensing devices are used thus assume considerable importance in jet-engine operation. Various methods for determining response rates have been worked out, but in most cases they have proved unsatisfactory because they failed to simulate operating conditions adequately.

Recently A. I. Dahl and E. F. Fiock of the National Bureau of Standards have developed apparatus [1] which determines the rate of response of jet-engine temperature elements under conditions very closely approximating those obtaining in the combustion stream. With this equipment, response times as short as 0.02 second have been measured for a wide variety of thermocouples, resistance thermometers, and thermistors.

The rate of response, or "characteristic time," of a specific temperature element (defined as the time required by the element to undergo 63.2 per cent of the total change in temperature to which it is subjected) depends on its mass, surface area, and heat capacity, and on the rate at which heat is transferred to the element from the gases flowing through the engine. Thus, in any test system in which heat is transferred to the temperature element mainly by radiation or natural convection, the observed values would not be applicable to jet engines. The Bureau therefore developed a system for studying characteristic times in which heat is transferred primarily by forced convection, as actually occurs in engines.

This apparatus consists essentially of a jet-engine combustor, or burner, with provision for mounting instruments in the exhaust gas stream, and a device for producing rapid changes in the temperature of the mounted test instrument. A compressor or blower supplies air to a single Jumo 004 turbo-jet engine combustor equipped with its normal fuel injector and spark plug. Exhaust gases from the combustor pass through two 90-degree turns, through a perforated plate, and then through about 10 ft. of straight pipe before reaching the test section, which has three convenience hatches for mounting instruments. In this way, the gas stream is kept at essentially uniform temperature and velocity over the central half diameter of the test section, and

[1] For further details, see Response characteristics of temperature-sensing elements for use in the control of jet engines, by Andrew I. Dahl and Ernest F. Fiock, *J. Research* NBS 45 (1950) RP2136.

exposure of any instrument to direct radiation from the flame is prevented by the turns in the duct system.

The gas temperature and flow rate at the combustor outlet are controlled by means of a valve at the inlet to the compressor and by adjusting the fuel pressure. A bleed line containing a butterfly valve also provides an auxiliary control of the flow in the test section, independent of the operating conditions of the burner. Pressures observed with a pitot-static tube, together with the known value of gas temperature, permit calculation of the mass flow rate in the test section.

For measuring rate of response, the temperature of the gas surrounding the test instrument must be changed very suddenly. This cannot be accomplished with sufficient rapidity by controlling the combustor. Apparatus was therefore developed for quickly immersing the instrument without altering the steady flow of exhaust gas in the test section. In this device, an Inconel tube, projecting vertically upward through the test section and held in position around the test instrument by a release plate, provides a flow channel for cold air. When the release plate is pulled out of the way, a spring suddenly removes the tube, exposing the instrument to the hot gas of the main stream almost instantaneously. During the downward movement of the tube, the supply of cold air is stopped automatically. In this way a test instrument at a known, moderate temperature (controlled by the air rate through the Inconel tube) can be brought in contact with exhaust gas at any given temperature and at any mass flow rate within the capacity of the system.

Two systems of this kind are now in operation at the Bureau. Air for one is supplied by a blower with a capacity of 4000 cu. ft. of free air a minute, and air for the other is provided by centrifugal compressors having a combined capacity of 10,000 cu. ft. per minute. The systems have identical Inconel test sections, about 6 in. in diameter. The second system can be operated at temperatures up to about 2000° F., and at mass flow rates up to 15 lb. per sec. ft.^{2} in the 6-in. test section. A test section 3 in. in diameter is used in endurance tests and in research where velocities up to 1800 ft. per sec. are of interest.

The apparatus has been used at the Bureau to study the performance of temperature-sensing elements exposed directly to the gas stream, elements encased in metal and ceramic protection tubes, and elements imbedded in insulating materials such as quartz and beryllia. While the equipment was designed primarily to subject the test junction to a sudden increase in temperature, characteristic times for the cooling process have also been obtained. This was done by heating the test junction electrically while it was surrounded by the Inconel tube, then subjecting it to a stream of unheated air. Results were found to agree with the theory which applies for heat transfer by forced convection; that is, the characteristic time at a given mass flow rate was the same, whether the instrument was heated or cooled.

FIELD-INTENSITY STANDARDS AT VERY-HIGH FREQUENCIES

The National Bureau of Standards is now offering a calibration service for field-intensity meters at all radio frequencies of broadcast and commercial importance up to 300 megacycles. Of special interest are the new standards and methods which have been developed at the Bureau for calibrating field-intensity meters in the very-high-frequency region from 30 to 300 megacycles. The new standards were developed to meet a need for an improvement in the available accuracy of field-intensity measurements required because of the greatly increased use of VHF bands by FM and TV stations. Prior calibration service for field-intensity meters had already accommodated meters operating in the range from 10 kilocycles to 30 megacycles.

Commercial field-intensity meters are universally used by broadcast engineers to determine the antenna efficiency and coverage of a radio station. The calibration of such instruments must be based on standards which are derived from and agree precisely with the basic units of measurement.

The extended field-intensity-meter calibration service necessitated the development of new and accurate field-intensity standards. The VHF standards are similar to those already employed at lower frequencies, but several special techniques, particularly in the measurement of antenna current and voltage, have been developed to meet the peculiarities of VHF calibration work.

Two distinct experimental methods are used in the Bureau's field-intensity standardization work: the standard-antenna method and the standard-field method. Both methods have been employed in establishing the standards used in calibrating commercial field-intensity meters. It has been found most practical to use the standard-antenna method for frequencies greater than 30 megacycles, and the standard-field method for lower frequencies.

In calibrating a commercial VHF field-intensity meter by the standard-antenna method, the field strength at some arbitrary distance from a special VHF transmitter is determined by a standard receiving antenna employing a crystal voltmeter. The antenna of the commercial set is substituted at the same position. Knowledge of the field strength, the height of the antenna above ground, and the meter readings obtained with the two antennas enable one to compute the antenna coefficient that must be applied to the commercial instrument to relate field intensity to its meter reading.

The standard-field method of calibration at frequencies below 30 Mc. utilizes a known induction field produced by a single-turn transmitting loop antenna. Relatively short distances are employed between transmitting and receiving loops so that reflections from the ground and nearby objects are minimized. The antenna coefficient of a commercial meter placed anywhere in the known field can be calculated on the basis of the known field strength, and the distance between the two antennas.

BOOK REVIEWS

OLD FRENCH IRONWORK: THE CRAFTSMAN AND HIS ART, by Edgar B. Frank. 220 pages, plates, 18 × 25 cm. Cambridge, Harvard University Press, 1950. Price, $6.00.

If the time should come in this mass production age when we shall lose our admiration for the work of the handcraftsman our lives will be the poorer and shabbier. Modern manufactures have put into the hands of common people numerous articles which were denied their ancestors and, if this represents a social gain, it is a loss in other fields. Workers have lost their individuality and buyers their discrimination, for they must now take what millions of others have. The art of everyday life has suffered. Only a few discriminating amateurs today practice handcraft and strive to make useful things beautiful.

Yet, when we see in museums and private collections the treasures of early craftsmen who made articles for everyday use we cannot restrain our admiration. The work of the smith is a notable example. Beating the iron while it was incandescent, modeling it with his hammer as a sculptor would model clay with his hands, compelled to work fast while the iron was hot, the craftsman needed a quick eye, a sure hand, and a clear head. Only those who possessed these qualities could hope to succeed. From the smith's anvil came locks, keys, seals, hinges, knockers, candlesticks, nutcrackers, and a multitude of devices, all designed to serve a practical purpose, and many executed with exquisite taste. The men who are doing the best work today turn back to these specimens for their inspiration.

There is much more to the study of old ironwork than old iron. Mr. Frank says that he has been led into a diversity of other subjects, ranging from mediaeval surgery to the art of heraldry, and that he has been a diligent student is clear from his book. If anyone should be inclined to complain that the study is too restricted, being limited to the work of the French smiths, it can be said in the author's defense that France offers an exceptionally rich field for handsome specimens of ironwork from the fifteenth to the eighteenth centuries. The variety is great and the general level of quality is unsurpassed.

Mr. Frank's acquaintance with the work of the smiths began when he visited the "flea market" and acquired some mediaeval padlocks. These so stirred his imagination that he has devoted forty years to the pursuit of similar small wrought iron treasures. This volume gives an account of his rewards. The book is devoted to the smaller types of ironwork and to the tools and methods by which these were produced. It is a book which no collector could afford to omit from his library, and can be strongly recommended to everyone who has a small workshop in the cellar of his home. The ninety-six plates, illustrating some five hundred objects, are excellent, and if we have any complaint to make about the text it is that there is not enough of it. What there is of it is so good that it merely whets the appetite and makes us want more.

A review of this book would be incomplete if it did not include a word of praise for the publishers, who have produced a book that is a joy to the eye and a pleasure to read.

T. C.

COLLOID CHEMISTRY, THEORETICAL AND APPLIED, Volume VII, collected and edited by Jerome Alexander. 736 pages, 16 × 23 cm. New York, Reinhold Publishing Corp., 1950. Price, $15.00.

This book is a collection of 43 papers, authored in many instances by acknowledged leaders in their fields. The relation of several of these papers to colloids appears somewhat strained, though their contents are interesting reading. Actually, this 736 page volume contains a considerable amount of material not usually found in a standard text on colloids. Such papers as, "The Intermediate-Compound Nucleus in Nuclear Reactions," "Luminescent Solids," "Blood Groups," "Dental Caries," "The Tubercle Bacillus" would rather surprise the average student in the field of colloids. Their presentation, however, capably shows that their inclusion in the field of colloids is amply justified.

The book is divided into three parts: theory and methods, biology and medicine, and technological applications. In theory and methods the theoretical and mathematical treatments are comprehensive and at postgraduate levels. In several of the papers the development of some of the theory is traced from the beginning. The work is well organized and voluminously referenced.

In part two the relation of colloids to biology and medicine is discussed. The significance of colloids in the biological processes of the living organism is gone into in some detail. Adsorption, interfacial reactions, spreading, and emulsification in these biological processes are described, as are the interactions of small ions and proteins and their effects on body functioning. The chapter on blood groups relates the field of immunology to colloids, and makes apparent the increasing importance of colloid science in the medical field. The colloidal activity of drugs, enzymes, and bacteria is briefly but well discussed.

Part three is devoted to the applied aspects of colloids, and the subjects range the entire industrial spectrum. These subjects include clays, asphalt, detergents, cellophane, margarine, cosmetics, soils, carbon black, and many others. A somewhat theoretical explanation accompanies a discussion of the uses of the material and problems in each industry.

On the whole, it is a valuable book, both for study and reference.

S. N. MUCHNICK

THE PLANET MARS, by Gerard De Vaucouleurs, translated from the French by Patrick A. Moore. 87 pp., illustrations and diagrams, 14 × 22 cm. New York, The Macmillan Co., 1949. Price, $2.00.

Every so often there appears a "sleeper" in the literary world. A book with little fanfare which suddenly enjoys a tremendous circulation. Books on science as a general rule do not fall into that enjoyable category but every so often there appears an "Atomic Energy for Military Purposes" or "The Universe and Dr. Einstein." *The Planet Mars* may be such a book.

There are several reasons why this book should enjoy a wide circulation. Primarily the book is about a planet whose very name is synonomous with mystery. Also it contains a complete resume of our knowledge concerning the planet as up-to-date as a new photograph taken with the giant 200-in. telescope.

In its content we find chapters describing the polar caps, the bright regions, the Martian atmosphere, the climate, the dark regions and finally there is a full and complete discussion of the canals of Mars. All these chapters have been illustrated wherever possible which makes the book a source book for information on the red planet.

In the discussion of the canals of Mars, De Vaucouleur neglects to point out that one of the principal tasks of the new 200-in. telescope is the photography of Mars using an automatic motion picture camera during the next favorable opposition in 1954 as described in an article in the Publications of the Astronomical Society of the Pacific in June 1947 by Edison Pettit. The astronomer sincerely hopes that some time following that opposition the question of the canals of Mars will be one more problem which will no longer disturb the scientist.

The Planet Mars belongs in the library of every astronomer.

I. M. LEVITT

ENGINEERING HYDRAULICS, edited by Hunter Rouse. Proceedings of the Fourth Hydraulics Conference, Iowa Institute of Hydraulic Research, June 12-15, 1949. 1039 pages, diagrams, 15 × 23 cm. New York, John Wiley & Sons, Inc., 1950. Price, $15.00.

Treatises have been written separately on the fundamentals of fluid flow, on flow measurement, on water hammer, on hydrology, on ground water flow, on hydraulic machinery, and, in fact, on any of the various aspects of hydraulics. But, *Engineering Hydraulics* is the first volume, in this country, at least, to contain treatments of all the applications of the science of hydraulics. It was with this purpose—of compiling a single, comprehensive reference book on hydraulics—that the Iowa Institute of Hydraulic Research formulated a plan for a complete presentation of engineering hydraulics. Following many discussions, an outline of the treatise evolved, and in 1947 such outstanding men in the various branches of hydraulics as J. E. War-

nock, late chief of the Hydraulics Laboratory, U. S. Bureau of Reclamation; J. W. Howe, Head of the Department of Mechanics and Hydraulics, Iowa State University; C. E. Jacob, Head of the Department of Geophysics, University of Utah; and V. L. Streeter, Director of Fundamental Fluids Research, Illinois Institute of Technology, were invited to contribute chapters. Before the book appeared in late 1950, each draft had been painstakingly criticized, correlated with the others and edited, the final critical review forming the subject of the Fourth Hydraulics Conference at the Iowa Institute, attended by some four hundred engineers from the United States and twelve foreign countries. Few books can claim such a thorough editing before publication; indeed, few can claim such after publication. As a result, *Engineering Hydraulics*, written in a fluent, understandable style, is not only an unusually comprehensive exposition of hydraulics, but an uncommonly authoritative one as well. It should become a standard reference on engineering hydraulics; certainly, it will be one of the best.

With such exhaustive editing, it follows naturally that the arrangement of the thirteen chapters comprising the volume should be in a logical sequence. The first three chapters—the fundamental principles of flow, by Hunter Rouse; hydraulic similitude, by J. E. Warnock; and flow measurement, by J. W. Howe—provide the hydraulic engineer with the theoretical tools. So equipped, the engineer or student can more easily grasp the specific subjects that follow: hydrology, by G. R. Williams; steady flow in pipes and conduits, by V. L. Streeter; surges and water hammer, by J. S. McNown; channel transitions and controls, by A. T. Ippen; and gradually varied channel flow, by C. J. Posey. Flood routing by B. R. Gilcrest, wave motion by G. H. Keulegan, and sediment transportation by Carl B. Brown complete the material associated with the usual civil engineering aspects of hydraulics. The final chapter by James W. Daily on hydraulic machinery surveys this relatively new branch of hydraulics rather thoroughly, including as it does the theory of turbo-machinery, centrifugal and axial-flow pumps, propulsion machinery, hydraulic turbines, hydrodynamic transmissions, and positive-displacement machinery. As a consequence of the fine editing, the reader is unaware of the book having been written by different authors; the same easy style and the same approach to each new subject—introduction, basic theory, application with frequent, very helpful illustrative examples, and references—prevail throughout, so the reader need not adjust himself continually to a new style of presentation.

In a book of such an ambitious scope, it is manifestly impossible to include everything on the subject. No doubt more could have been included on certain of the branches, perhaps on sediment transportation and hydraulic machinery; but condensations and omissions were made only in the considered judgment of the Iowa Institute staff and their Board of Consultants, and were necessary in order that the finished book not be unwieldy. However, in its final form, *Engineering Hydraulics* is unquestionably a major engineering publication of 1950 and a noteworthy contribution to scientific literature.

E. W. HAMMER, JR.

JOEL MUNSELL: PRINTER AND ANTIQUARIAN, by David S. Edelstein. 420 pages, 15 × 22 cm. New York, Columbia University Press, 1950. Price, $5.00.

Joel Munsell was one of the outstanding American printers of the nineteenth century who, though appreciated by his contemporaries, had sunk into relative obscurity until a decade or so ago. One of those contributing to the revival of interest in Munsell is Professor Hellmut Lehmann-Haupt of Columbia University, to whom Dr. Edelstein acknowledges his indebtedness for inspiring this biography. The present reviewer can also testify to the Professor's contagious enthusiasm for Munsell, which has resulted in his looking forward to the present volume with interest.

Born in 1808, Joel Munsell began his printing career as an apprentice in Greenfield, Mass., in 1825. Dr. Edelstein follows his wanderings, typical of so many early printers, until he finally established his own press in Albany. In several respects Munsell's early career paralleled that of his earlier, more famous, fellow craftsman, Benjamin Franklin. Munsell was conscious of the resemblance of habits in his daily life to those of Franklin, and in 1828 copied into his diary Franklin's rules for spending the twenty-four hours of the day. Later, when

Munsell took over *Webster's Calendar* in 1844, he was to announce proudly that after Franklin's *Poor Richard* and Isaiah Thomas' *Almanac*, *Webster's* was the most famous almanac in the country.

In discussing the activity of Munsell's press, the author divides his account into two periods, at 1850. Before that date Munsell's printing activities were those of any general printer—books, pamphlets, newspapers and job printing. After that date, although he maintained the general nature of his business, he doubled his average annual output of books and pamphlets and specialized in printing books of antiquarian interest. The second period also saw Munsell engaging actively in the publishing and bookselling business in addition to printing.

After the chapter reviewing the chronological development of Munsell's business, Dr. Edelstein presents four chapters on particular phases of Munsell's career. These discuss practical problems of the printing business, Munsell's activities as a scholar printer, as reflected in his compilations on the history of printing and in his efforts at fine printing, his career as a publisher and bookseller, and his role as an antiquarian in compiling historical works and in actively supporting numerous historical societies. These chapters are undoubtedly the most significant in revealing the varied facets of Munsell's career and in assessing his place in nineteenth century America.

A final chapter presents the domestic facts relating to Munsell's Albany period and reviews briefly the subsequent history of his firm. Dr. Edelstein has had the benefit of conversations with Munsell's youngest daughter, which has enabled him to present facts otherwise not available. He has also uncovered much manuscript material, which is detailed in a lengthy bibliography along with many printed sources. The author has provided considerable background material, especially on the state of the printing art, which provides for a better understanding of Munsell's activities.

This reviewer must confess, however, to a certain disappointment in this book. He would have liked a fuller assessment of Munsell's activities as a printer of books of distinction, for he feels that this is one of the major bases for Munsell's claim to recognition as a printer. Also, this reviewer noticed several errors, mostly typographical, which seem strangely out of place in a book on one who printed many fine books.

Notwithstanding these criticisms, the reviewer gladly recommends the book to anyone who wishes to know more about Joel Munsell, and he suggests its perusal to all who would read about a leading practitioner of the art of printing.

GEORGE PETTENGILL

TRANSMISSION LINES AND NETWORKS, by Walter C. Johnson. 361 pages, illustrations, 16 × 23 cm. New York, McGraw-Hill Book Co., 1950. Price, $5.00.

This new book by Professor Johnson treats very much the conventional subject matter of an undergraduate electrical engineering course in transmission lines. The first part of the book, after introducing some basic concepts, considers special cases which are encountered in radio frequency, telephone and telegraph, and power transmission lines. The second part of the book considers the general theory of four terminal networks, with special application to attenuators, impedance matching, and filters.

Traveling waves on transmission lines are considered early in the text, providing a basis for the treatment of the special cases. Of particular interest is the chapter devoted to the construction and use of the rectangular and circular (Smith) transmission line charts. To help the reader understand the advantage of these charts for computational purposes, several problems are worked out in detail.

Radio frequency transmission line problems are adequately treated. Numerous sketches show the basic construction of instruments used for radio frequency measurements and of stub tuners. These always help the student to obtain a clearer picture, especially if he does not encounter similar devices in a laboratory course.

Four terminal networks are presented in the standard manner. Following a chapter on network theorems, various impedance relationships are derived, and the simple filter and attenuation sections are designed.

For some unexplained reason the author separates the chapters on transmission lines with no reflections and with reflections by one on the constants of two conductor lines. It would seem more proper that such a chapter should either precede the discussion of transmission lines or appear as an appendix.

S. CHARP

CAPACITORS FOR INDUSTRY, by W. C. Bloomquist and others. 246 pages, illustrations, diagrams and tables, 15 × 23 cm. New York, John Wiley & Sons, Inc., 1950. Price, $4.50.

With the trend toward specialization in engineering, it is apropos that a book should be devoted to the industrial applications of capacitors. This volume is one of a series written by General Electric authors for the advancement of engineering practice.

The ability of capacitors to reduce power costs, release electric system capacity and improve voltage regulation gives them an important economic value. During recent years their use has steadily increased in power system and industrial applications where power factor improvement can be achieved. Probably because of the great economic importance of this subject, roughly one third of the book is devoted to the many aspects of power factor improvement.

With emphasis on the means of accomplishing results, prepared curves and tables are supplied together with illustrative examples. The concept of a capacitor as a kilovar generator is introduced to provide a convenient means for manipulating the wattless power which it furnishes. The broad use of capacitors in allied commercial fields such as high-frequency heating is discussed briefly with the idea of describing special types of capacitors (water-cooled, for example) which have been developed to meet particular needs.

For completeness, the authors have included information on capacitor design, construction, characteristics and methods of rating. This augments the applications engineer's knowledge by supplying some of the "why" to go along with the "how" of the presentation.

The book is not in any sense a text for college instruction purposes. Rather it is a working reference in practical engineering and should be of special interest to electrical power men. It is written so that any technician familiar with the terms applied to electrical power equipment and able to understand elementary trigonometry can put most of the book's contents to use. The large number of charts, tables, numerical examples, circuits, vector diagrams, and photographs of modern equipment gives the volume certain qualities of a practical handbook on capacitors for power applications.

C. W. HARGENS

MATHEMATICAL SNAPSHOTS, by H. Steinhaus. 266 pages, illustrations, 14 × 22 cm. New York, Oxford University Press, 1950. Price, $4.50.

Mathematics is an intriguing subject, but all too often an unimaginative teacher can make it very dull. Here is a different mathematics book that will kindle your interest.

It is a book of games, puzzles, tricks, mathematical oddities and problems. Some of these are very simple and some require a knowledge of high school algebra. However, the book is profusely illustrated, averaging better than one picture to a page. As some ancient Hindu proofs are labeled "Look," the author also believes that much can be gained by looking.

Professor Steinhaus selected a variety of subjects which include discussions of soap bubbles, how the honeycomb structure happens, how to construct Mobius bands, tie knots and color maps. Practical subjects are treated, such as how to locate schools, divide cake or property fairly, and fix the position of an object located by X-ray so that a surgeon can operate. The geometrical designs in two and three dimensions, and the relation of musical concords to numbers will interest the artist.

Mathematics can prove that some games can always be won by the starter, others will end in a draw, and still others give each player an equal chance if the games are played without making mistakes. All three kinds of games are illustrated. In the same way, some puzzles can be solved and some are impossible to solve. Our Polish mathematician illustrates many of these and gives the solutions or proof of no solution. He asks many questions but does not

answer all of them. In fact, some of them he cannot answer. However, he does solve the following problem.

If you have 13 coins and one of them is counterfeit as shown only by a difference in weight, determine how to locate the counterfeit coin in three weighings. We don't know whether the counterfeit coin is heavier or lighter than the standard coin.

This book will interest the layman, the mathematician, and the engineer. In fact, there are some things in it which should interest everyone.

E. A. MECHLER

QUAKERS IN SCIENCE AND INDUSTRY, by Arthur Raistrick. 361 pages, plates and diagrams, 14 × 22 cm. New York, Philosophical Library, 1950. Price, $6.00.

Here is an interesting and instructive side-light upon the Industrial Revolution, in which is traced the pattern of Quaker activity that led to the promotion of some large industries and banks. Dr. Raistrick is prominent in England, both as a scientist and as a Quaker, so that he is competent to undertake his task. He furnishes a sketch, not lacking in detail at essential points, of the origin and growth of the Society of Friends, and describes the incidence of certain statutes, such as the Conventicle and Test Acts, which excluded members of the faith from the universities, higher education, and the professions for several generations. This legal exclusion diverted many fine minds into other channels. Their simple and frugal way of living suited them to the development of those industries where speculation was to be avoided and where the returns were not immediate.

By nature of the external pressure upon them, the Quaker industries became a close network of concerns tied together by family relationships. This is particularly noticeable in their ironworks and banks, although no small business stood entirely alone, but was helped over difficult times by "cousins." However, this does not account for the number of Quakers named by Dr. Raistrick who became botanists.

This book gives a good comprehensive account of those industries in which Quaker influence had its greatest impact, and it traces their incursions into trade and finance. We should have liked to see the American Quaker treated more fully. The book deals essentially with the English picture and deals only with the few Americans, like James Logan and John Bartram, who had associations with England. One would have thought that Maria Mitchell would have qualified for inclusion as an outstanding figure in astronomy and female education in America. She would have been a reinforcement to the scientists who scarcely figure in the book as prominently as the title implies.

The author shows that the Quakers played an energetic part in the basic industry of the eighteenth century, and deals in separate chapters with their activities as traders and merchants, as ironmasters, and in the mining companies. In science the clock and instrument makers, the botanists and naturalists, and the medical doctors are treated adequately. Finally, those Quakers who built up the great banking houses are treated apart. Dr. Raistrick exhibits the scruples of the Quaker for superfluities and writes with a granular style that flows as smoothly as dry sand. The book is a fine piece of literary research and merits the attention of the student of industrial history.

The reader who is inclined to deplore the absence of the spiritual element from modern life will rejoice in this exposition of a people who, refusing to separate the things of the spirit from their daily occupations, became a source of strength in industry and commerce and who, while persecuted as a sect, yet succeeded in gaining public confidence.

T. C.

INDUSTRIAL HIGH FREQUENCY ELECTRIC POWER, by E. May. 355 pages, illustrations, 14 × 22 cm. New York, John Wiley & Sons, Inc., 1950. Price, $5.00.

While the subject of high frequency electric power has been treated to some extent in periodical literature, the author here lucidly presents the basic facts used in the application of electricity and electronics to induction and dielectric heating. Following an introductory summary of elementary circuit theory which emphasizes the simple coupled circuit and the

concept of transferred impedances, three chapters are devoted to the basic methods of generating high frequency power: arc and spark oscillators, high frequency alternators, and vacuum tubes. The design of Class B and Class C power amplifiers with tuned loads is treated in a detailed manner with worked out examples to show the steps which are usually followed in a practical design for high frequency heating applications.

Considerable attention is devoted to: the problems of the current distribution in various shaped charges and the power developed in them; the design of work coils, transformers, and feeders for various applications such as surface hardening, melting furnaces, and brazing; and methods of coupling for both induction and dielectric heating. Power supplies, timing mechanisms, and high frequency measurements of the electric and magnetic variables are discussed descriptively. A final chapter treats industrial applications and operating problems, with reference to numerous particular processes and pieces of equipment.

Although not evidently intended as an undergraduate text, it is felt that the book could be admirably used for in-service training of engineers in the subject field. Needless to say, it can well serve as a ready reference to practical problems for electrical engineers and physicists who encounter problems in high frequency heating.

S. CHARP

TRANSMISSION LINES AND FILTER NETWORKS, by John J. Karakash. 413 pages, diagrams, 16 × 24 cm. New York, Macmillan Co., 1950. Price, $6.00.

Intended as an undergraduate college level text, this book covers the subjects of transmission lines and filter networks quite thoroughly. The text is divided into three major sections devoted, in order, to steady-state transmission line theory, transmission networks, and electric wave filter theory. A fourth section consists of appendices covering Maxwell's equations and matrix algebra.

In Section One, the author develops transmission line theory from the basic differential equations of the transmission line. He then discusses a number of the properties of transmission lines such as the propagation constant, characteristic impedance, line terminations and standing waves, transmission efficiency, etc.

Section Two deals with certain transmission parameters, sets forth the basic network theorems, and then goes into the development of the artificial line. This section leads into the development of filter theory covered in Section Three, in which the author covers K filters, M filters, and lattice filters using lumped constants and then takes up filters using sections of transmission lines as elements.

Throughout the text the material is well presented and is supplimented with up-to-date tables and charts. There are numerous problems at the ends of chapters to test the students' grasp of the subject.

ROBERT S. GRUBMEYER

THE PRIVATE LIFE OF THE PROTOZOA, by Winifred Duncan. 141 pages, plates, 24 × 16 cm. New York, The Ronald Press Co., 1950. Price, $3.00.

Natural History is a fascinating study. Unfortunately, like so many of the physical sciences it is a highly specialized field open only to the diligent reader. In these hurly-burly days of the modern civilization the opportunity to delve into the mysteries of the microscopic world is usually missing.

For this reason a book like *The Private Life of the Protozoa* is a welcome addition to the library. In a delightfully narrative and facile style the author introduces those tiny creatures which live in a sub-world and are seldom seen. This book endows these creatures with a personality which insists on a personal acknowledgement of their existence. Because of the reviewer's experience with a microvivarium this book assumes special significance.

This is vivid and dramatic writing skillfully woven around an action which, to us, is almost non-existent. The reviewer has often wondered how the tiny organisms react to a finger being pushed through a pool of water they call home. The finger moves faster in a split second than these tiny creatures move in their entire lifetimes. To us it is as though an

asteroid came hurtling out of the sky with an incredible speed and brushed the earth in its flight. We might get used to it but it would always appear mighty impressive.

As a consequence of reading Miss Ducan's latest book the next time a trip to the country is contemplated it will be with a magnifying glass. Like *Webs in the Wind*, this book is highly recommended.

I. M. LEVITT

CASTING AND FORMING PROCESSES IN MANUFACTURING, by J. S. Campbell, Jr. 536 pages, illustrations, diagrams and tables, 16 × 24 cm. New York, McGraw-Hill Book Co., 1950. Price, $5.00.

As Professor Campbell of Rensselaer Polytechnic Institute emphasizes, many engineers entering the field of machine design will require a background in the various manufacturing processes in order to design properly. Aware of how his machine will be produced, the engineer can design more efficiently and more economically. Thus, with this very worthy purpose of providing a sound education in all the casting processes as plastics-molding and forming, powder metallurgy, rolling, forging, sheet-metal working, and punch-press operations—in short, all the manufacturing processes—Professor Campbell has prepared *Casting and Forming Processes in Manufacturing*. Wisely, companies and corporations using the various processes have been consulted, so much practical, first-hand information comprises a large part of the book.

Since sand casting is the most versatile method of producing castings and the most important, more than half of the text concerns this method of manufacturing. From the making of a simple mold, through patternmaking and equipment, molding materials and equipment, molding techniques, types of molds, solidification and risering, molding machines, cores and core making, types of sands and sand testing, sand casting defects and sand casting design, to the cleaning, finishing and inspection, the whole subject of sand casting is thoroughly explored. Such practical and useful information as rules for gating castings, likely sources of casting defects, and rules for sound sand-casting design are included.

Following the treatment of sand casting, Professor Campbell discusses centrifugal casting, precision investment casting (the lost wax process), permanent mold casting, die casting, the molding and forming of plastics, powder metallurgy, rolling and forging, sheet-metal working and punch-press work. While these subjects are not so detailed as sand casting, nevertheless the student will easily obtain a working knowledge of the various processes from a study of the material. Included in the book also, are chapters on the organization, modernization and mechanization of foundries.

E. W. HAMMER, JR.

CHYMIA, ANNUAL STUDIES IN THE HISTORY OF CHEMISTRY, Henry M. Leicester, Editor-in-Chief. 250 pages, illustrations, plates, 16 × 24 cm. Philadelphia, University of Pennsylvania Press, 1950. Price, $4.50.

It is again a pleasure to take in hand a volume of *Chymia* and to comment on its contents. This third volume is introduced by a tribute to an outstanding historian of chemistry, Tenney L. Davis, editor of the first two volumes of *Chymia*. Henry M. Leicester and Herbert S. Klickstein have joined in presenting an evaluation of Mr. Davis' contributions to the history of chemistry, notably by his studies in Chinese alchemy which were of first importance in opening up a new and hitherto unexplored field. A bibliography lists Mr. Davis' numerous writings on chemical history.

Of the remaining dozen articles, that of most immediate appeal to Philadelphians is by Wyndham Miles on "Early American Chemical Societies." In this he traces the history of the Chemical Society of Philadelphia which was established in 1792 and disbanded sometime prior to 1810. Mr. Miles has gathered together much information concerning the society's activities, its officers, and even an extensive list of members. Of especial interest is the fact, that in the course of his researches, he discovered an allusion to an even earlier Philadelphia chemical society of 1789, the existence of which had hitherto been unknown. Gradually the

history of these early societies is being pieced together, and it is perhaps worth noting here that the Chemical Society of Philadelphia once owned Franklin's electrical machine.[1]

Dr. George Sarton offers an illuminating discussion on "Boyle and Bayle—The Sceptical Chemist and the Sceptical Historian." A parallel treatment presents the main facts of their lives and their principal ideas, while two concluding chapters offer a final comparison and a conclusion. As representatives of the golden age of science and of learning of the second half of the seventeenth century, Boyle and Bayle were instrumental in providing the sceptical spirit in chemistry and in history which permitted the successful later foundation of modern chemistry and historical criticism.

Studies of Karl Friedrich Mohr, 1806-1879—"Father of Volumetric Analysis" by John Mark Scott, and Henri Sainte-Claire DeVille, 1818-1881, by Ralph E. Oesper and Pierre Lemay present a review of the work of these two nineteenth century chemists. Mohr made many improvements in chemical apparatus in addition to his great contribution to analytical chemistry in his textbook on volumetric analysis. Deville did much interesting work on aluminum and on dissociation, the use of which term he originated.

In a lengthy article I. Bernard Cohen investigates "The Beginning of Chemical Instruction in America" in which he recounts what he has discovered concerning the teaching of chemistry at Harvard prior to 1800. He finds that the introduction of Charles Morton's "Compendium Physicae" in 1687 "marks the beginning of collegiate instruction in chemistry in the British Colonies."

In an illustrated article Maurice Daumas discusses some of the experimental apparatus used by Lavoisier. Rudolf Hirsch has compiled a checklist of the different printed editions of various chemical writings up to 1536 under the title "The Invention of Printing and the Diffusion of Alchemical and Chemical Knowledge." References are given to various bibliographical sources for further details. Other papers are "Bio-Active Substances in the Nineteenth Century" by Eduard Farber; "La Química en los 'Éléments de Chimie' de Orfila" by Carlos E. Prélat and Alberto G. Velarde; "Wandlungen in der geschichtlichen Betrachtung der Alchemie " by W. Ganzenmüller; and "Bunsens Vorlesung über allgemeine Experimentalchemie" by Heinrich Rheinboldt.

A concluding article by Claude K. Deischer and Joseph L. Rabinowitz discusses the origin and significance of the owl of Heinrich Khunrath which the editors of *Chymia* have chosen for use as a vignette on its title page. The editors may again be congratulated for securing a varied selection of articles with an international representation of authors.

GEORGE E. PETTENGILL

SURVEY OF MODERN ELECTRONICS, by Paul G. Andres. 522 pages, illustrations, 14 × 22 cm. New York, John Wiley & Sons, Inc., 1950. Price, $5.75.

This book is an excellent survey of Modern Electronics. The numerous specific applications used to illustrate the fundamental theory make interesting reading and cover the whole field of electronics. The book is intended to be used as a text for a survey course in electronics for both electrical and non-electrical engineers, and it does fulfill this purpose.

The subjects covered are the fundamental physical concepts of electricity and conduction, the theory and application of diodes, triodes, multigrid and special vacuum tubes, and the theory and application of gas filled tubes and photo tubes. Additional chapters are devoted to the application of electronics to instrumentation, communication and navigation, controls for heavy equipment including motors, generators and welding equipment, and induction and dielectric heating. A great number of pictures and schematic diagrams are used to illustrate the specific applications. These allow the reader to gain a better idea of the size and complexity of the apparatus.

To illustrate the variety of examples discussed throughout the text, a few are cited below. Corrosion and rust can be prevented in tanks, standpipes, and other submerged metal surfaces by using a small current from a dry rectifier. Hospital operating rooms, meat packing plants,

[1] For details see note in this JOURNAL, p. 188.

bakeries, breweries and dairies use germicidal lamps to decrease infection and spoilage. Beef tenderizing plants estimate they increase their production 20 per cent by using germicidal lamps. Photoelectric equipment is used to sort beans. The bad beans have dark spots which can be detected by the sorter. Needless to say, the equipment does not work on black-eyed peas. Electronic analog and digital computers are discussed briefly and examples of gas engine analyzers are described. Records and diagrams of the electroencephalograph and the electrocardiograph illustrate medical instrumentation. Paper mills require precise speed control at an adjustable speed, but many other industries having simpler speed control requirements also use electronic speed controls. The author discusses electronic precipitation, the electron microscope, x-ray diffraction, automatic navigation equipment for aircraft, and high frequency heating.

This last application is a good example of the way electronics can increase production. Using high frequency heating equipment, a 30 lb. can of frozen cherries can be defrosted in 12 minutes instead of the 20 hours required by normal methods. This application is a great help to food processing plants.

The numerous specific examples and the descriptive, rather than the mathematical approach make this book very entertaining and easy to read and if the reader desires more nformation on any specific application, he can refer to the bibliography at the end of each chapter.

E. A. MECHLER

BOOK NOTES

REFRIGERATION ENGINEERING, by H. J. Macintire and F. W. Hutchinson. Second edition, 610 pages, diagrams, charts, tables, 15 × 24 cm. New York, John Wiley & Sons, Inc., 1950. Price, $6.50.

In preparing the revision of Professor Macintire's text, first issued in 1937, Professor Hutchinson has endeavored to increase its effectiveness both as a college textbook and as a reference book for practicing engineers. The chapters have been grouped into sections, new chapters added, especially in the section on reversed cycle theory, and over seventy additional illustrative figures are included. There are also over thirty full-page graphical solutions giving direct-reading values of the film coefficient of heat transfer for most of the commonly used refrigerants when being heated or cooled as either a subcooled liquid or a superheated vapor.

MECHANICAL ENGINEERING LABORATORY, by Charles W. Messersmith and Cecil F. Warner. 160 pages, illustrations and diagrams, 21 × 28 cm. New York, John Wiley & Sons, Inc., 1950. Price, $3.50 (paper bound).

This spiral bound booklet presents text matter to be used in a laboratory course in mechanical engineering. The use of the steady flow general-energy equation has been emphasized, and frequent reference has been made to test codes and procedures in order to familiarize the student with them.

CHEMICAL KINETICS, by Keith J. Laidler. 408 pages, diagrams, 15 × 23 cm. New York, McGraw-Hill Book Co., Inc., 1950. Price, $5.50.

Intended primarily as an introductory text for university students, this work presents the more important facts and theories relating to the rates with which chemical reactions occur. Easily divided into two parts, the book treats first of elementary reactions and second of the relation of the over-all rate of complex reactions to the rates of the individual steps. Adequate attention is given both to experimental data and the application of theory. Problems have been included and the more difficult ones are marked.

UPPER WINDS OVER THE WORLD, by C. E. P. Brooks and others. 150 pages, charts, tables, 21 × 28 cm. London, His Majesty's Stationery Office, 1950. Price, 17s 6d.

SOLAR RADIATION AT KEW OBSERVATORY, by J. M. Stagg. 37 pages, tables, diagrams, 21 × 28 cm. London, His Majesty's Stationery Office, 1950. Price, 3s 6d.

These two publications are Geophysical Memoirs Nos. 85 and 86, respectively, prepared by the Meteorological Office of the British Air Ministry. The first presents a discussion of the availability of data on the upper winds and then considers the preparation of seasonal charts of mean heights of isobaric surfaces, seasonal charts of winds at standard pressure levels in the tropics, and seasonal charts of standard vector deviation. Insofar as the necessary data are available, these charts have been presented for 700, 500, 300, 200, and 130 mb.

The second pamphlet considers first the continuous records of direct solar radiation at normal incidence, kept at Kew since 1932, and second, the measurement of total short-wave radiation on a horizontal surface from sun and sky together, and sun alone, made since 1946. A detailed discussion of the physics of the various topics involved is also provided.

STRUCTURAL THEORY, by Hale Sutherland and Harry Lake Bowman. Fourth edition, 394 pages, diagrams, tables, 15 × 23 cm. New York, John Wiley & Sons, Inc., 1950. Price, $5.00.

This undergraduate text dealing with the basic conceptions and principles of structural theory relating to trusses, rigid frames, and space frameworks has again been revised. Much of the text has been rewritten and new material has been added, including the solution of compound trusses by means of the Williot-Mohr diagram, and a brief explanation of the fixed points in continuous beams.

ORGANIC SYNTHESES: AN ANNUAL PUBLICATION OF SATISFACTORY METHODS FOR THE PREPARATION OF ORGANIC CHEMICALS. Volume 30, Arthur C. Cope, Editor-in-Chief. 115 pages, diagrams, 15 × 24 cm. New York, John Wiley & Sons, Inc., 1950. Price, $2.50.

This latest volume in an ever-growing series includes methods for the preparation of thirty-nine compounds. Following the pattern of earlier volumes, procedure, notes, and methods are given for each compound. The index begins a new cycle, as references are included only to this volume.

MODERN CHEMICAL PROCESSES, by the Editors of *Industrial and Engineering Chemistry*. 222 pages, illustrations, tables, and diagrams, 20 × 29 cm. New York, Reinhold Publishing Co., 1950. Price, $4.00.

This volume reprints in convenient form a series of twenty-three articles on American chemical processes which have appeared in *Industrial and Engineering Chemistry*. Having set a high standard, the editors have avoided the usual "puff" articles and instead have supplied, with the cooperation of the companies concerned, much solid matter in the fields of chemical manufacturing and engineering knowledge. Flow sheets have been featured and bibliographies provided. The processes cover a wide range: chlorine and caustic soda, chloriquine manufacture, paving asphalt and citrus fruit processing might be instanced. As an up-to-date source on chemical process industries, it should prove its usefulness, which it is planned to maintain by future biennial volumes of twenty-four articles each.

CURRENT TOPICS

Centennial of Engineering, 1952.—Eleven national technical societies and one from Canada have already taken formal action to participate in the international convocation which will celebrate one hundred years of engineering as an organized profession in the United States. This convocation, organized under Centennial of Engineering, 1952, Inc., is designed to "Provide an opportunity for all engineers to gather to exchange ideas and information of value to one another with no one group taking a place of special prominence."

At a meeting on October 12, 1950, the incorporators of Centennial of Engineering authorized President Lenox R. Lohr to extend invitations to an additional sixty technical societies in this country, and to appropriate societies of international scope, or of national scope in other countries. The international societies will be invited to hold their annual meetings in Chicago during the Centennial Convocation from September 3 to 13, 1952. Where it is not feasible for the societies of other countries to hold meetings in this country, it is hoped that they will send representatives to the convocation.

Before the year 1800, the only engineers were military engineers. For centuries they were the designers of fortifications, such as the noted Frenchman, Vauban, and were the keepers of the king's engines: catapults, battering rams and scaling towers. Elements of the civilian economy, such as bridges, roads, viaducts, mines and buildings, were built largely by artisans with empirical designs developed from the experiences of their predecessors. The small industries of the day—cotton and flour mills, stonecutters and shoemakers —were largely family concerns utilizing limited help from their neighbors and not requiring the service of engineers.

Up to this time the United States had lacked even military engineers, and during the Revolutionary War had utilized Europeans. In the year 1802, West Point was founded, not primarily as a training school for officers, but to develop military engineers, and while its basic function has changed, it has remained under the supervision of the Corps of Engineers ever since.

With the march of progress it was realized that engineering had a scientific and economic basis, so the Corps of Engineers was called upon to build such things as the Baltimore and Ohio Railroad. Even as late as the 50's, the lack of American engineers made necessary the use of British engineers in designing the Northwestern Railroad. And to this day the engines run on the left hand side of the track—according to the British practice.

With the introduction of steam power and the rapid economic expansion of the country, large manufacturing plants and major engineering works were developed and the need of civilian engineers was realized.

The first engineering school in the United States was Rensselaer Polytechnic Institute, which was established at Troy, New York, in 1824, and a new profession came into being. In the year 1852 the first national engineering society, the American Society of Civil Engineers, was formed. The connotation of civil engineer was quite different from that accepted today, being used only to differentiate them from the specialized work of the military engineer.

It included all branches of the engineering profession as well as architects. As the industrial revolution brought expansion of the small home industries to the giant concerns of today and as the amount of engineering knowledge increased, specialization became necessary. Various groups of engineers such as mining, mechanical, electrical and chemical formed societies of their own. But they all had their inception in the first national society of civilian engineers founded in 1852.

America today enjoys the highest standard of living of any nation in the world. With 6% of the world's population it has:

70% of the world's automobiles,
50% of the world's telephones,
48% of the radios, and we produce
32% of the world's manufactured goods.

Without the engineer with his scientific background, mass production and mass distribution as we know it today would have been impossible. In general he has been the unseen force behind management, operating under the aegis of the free enterprise system that has made the United States the most powerful and prosperous nation in the world.

As the one hundred years have passed since the founding of the American Society of Civil Engineers, and as the branches of the engineering profession have grown more specialized, engineers have become less generally informed about the activity of the profession at large. The Centennial Convocation will give the engineers of the country an opportunity to attend meetings and hear technical papers of the other branches of engineering, and to obtain pertinent information on the developments available to them from specialties outside their own fields.

An important part of the Centennial of Engineering celebration will be an Exposition during the months of July, August and September in 1952. The incorporators of the Centennial of Engineering have stated "The purpose of the Centennial Exposition should be to tell the story of engineering and industry to the general public." The story of engineering and industry is one story. To take either element without the other would be almost impossible. For this reason it is essential to the engineer that our industrial system be preserved on the same freely competitive basis on which it has been built.

This story will be told in many ways at the Exposition which will be held at the Chicago Museum of Science and Industry. First in public appeal will be a stage production in the thousand-seat main auditorium of the Museum. This show will be a dramatic human interest pageant about America, how it grew and prospered over the years, and how it can continue to grow. The essential role of the engineer and his industrial machine will be woven into the pageant just as it was woven into our daily lives.

A permanent engineering exhibit will be built in the Museum where it may be open to visitors in July of 1952, and during the years that follow. This exhibit, occupying over eight thousand square feet of floor space, will utilize dioramas, models, and full size equipment to show the evolution of engineering and of the engineer over the last hundred years. There will be examples of every field of engineering arranged to show how the products of dozens of different specialties come together to make one complete complex machine.

New Super Counter Shown at Nuclear Exhibit.—For the first time a commercial atomic energy instrument, including a completely new detector that will supersede the Geiger counter, has been placed on the market for use by hospitals, physicians, and clinics. The new machine, called the Isotron II, was announced for the first time at a meeting on Nucleonics in Medicine at the Park Sheraton Hotel. It is the result of years of work put into special counting equipment and developed by Nuclear Instrument and Chemical Corporation of Chicago.

The new detector, described by President James A. Schoke, as one which will make the Geiger counter obsolete, is called a "scintillation counter," and is at least 20 times as efficient as the Geiger counter. This detector is used in conjunction with a compact mobile unit 3 in. high with an array of controls on the top surface. It will be used for measuring radiation from patients who have been given "doses" of radioisotopes, and has a paper chart which is driven by a motor, with a pen to draw a permanent record of the patient's condition.

The new Isotron II is designed specifically for studying brain tumors, but is also used for checking cancers, thyroid, blood condition, and controlling the amount of radioactive isotopes given for treatment purposes. It is expected that soon every hospital clinic, and treatment center will be equipped with at least one of these new life saving products of the atomic age.

New Electronic Device Facilitates Color Measurement.—A simple new instrument, which for the first time enables quick and accurate measurement of color coming from a direct light source, was described by George C. Sziklai, physicist of RCA Laboratories, Princeton, N. J., at the annual meeting of the American Optical Society.

Called a "tristimulus photometer," the new instrument uses only five electron tubes and is no larger than a shoe-box. It simultaneously determines the relative strength of the three basic color components in a light source under study and gives an instantaneous reading. Previous methods of color specification, Mr. Sziklai said, require roughly one-half hour of measurement with a spectrometer followed by several hours of computation.

Though the spectrophotometric method gives a higher degree of accuracy, he said, the tristimulus photometer can give values of the three color components sufficiently precise for every-day engineering work and can readily distinguish between two different color samples which are close enough together in value so they would appear identical to the eye.

Designed specifically to provide a laboratory and studio check on the faithfulness of color reproduction in color television, Mr. Sziklai said that the instrument, since it can determine the values of a reflected light source as well as a direct one, might also have valuable application in the textile, paint and other industries where color matching is critical. He pointed out that a direct-reading electronic instrument had been designed by the National Bureau of Standards of the U. S. Department of Commerce, which can define the components of reflected light, but cannot handle a direct light source such as that of a television screen.

The new instrument consists essentially of an "eye" and a "brain." The "eye" is made up of a lens which focuses the light under study onto a mirror

assembly designed to split the beam into three parts of equal intensity, Mr. Sziklai explained. The three beams then pass through three filters, each sensitive to a range of wavelengths corresponding to the basic color components.

The "brain" of the instrument starts with three photocells, one for each filter. The photocells convert the light energy to electrical energy which passes through circuits, each of a different design, to compensate for the mathematical dissimilarities between the three color components. Finally, a corrected value for each component is read on microammeters.

The readings are in terms of the three theoretical basic components, as defined by the International Commission of Illumination, by which any color in nature can be described in standard terms. The filters select the closest real approximations to the theoretical primaries, which are referred to in colorimetry as X, Y and Z. Then the electronic circuits mathematically "shape" the actual values, transforming them to the theoretical values of I. C. I. color specifications.

The theoretical color values have no counterparts in the realm of actual colors. The use of the theoretical primaries is necessary in colorimetry to do away with the use of negative quantities of light in the mathematics of color definition. However, by employment of the theoretical primaries, a practical system of color measurement is attained.

Midget HV Electron Gun (*Electrical Equipment*, Vol. 10, No. 11).—Brookhaven National Laboratory is making available to qualified industrial scientists a midget sized (5′ long × 3′ diam) 2,000,000v electron gun. This tiny Van de Graaff generator can be used to study effects of radiation on the physical and electrical properties of various materials, particularly those used in the construction and operation of nuclear reactors.

"Lopsided Atom" Theory (*Industrial Laboratories*, Vol. 1, No. 2).—A "lopsided atom" theory, lifting some of the mystery from catalytic action—and thereby perhaps prefacing momentous developments in processing—was presented before the New York Academy of Sciences recently by Dr. W. A. Weyl, of the department of mineral technology, Pennsylvania State College. Dr. Weyl, whose work is sponsored by the Material Branch of the Office of Naval Research, can explain some unusual colors of crystal and certain trade secret processes by his theory, which also accounts for the so-called poisoning of compounds. Warping and crowding of atoms near the surface, by internal electrical fields which pull and distort them, makes the atoms work in an unusual—a catalytic—way, according to Dr. Weyl.

Bacteriology (*Industrial Laboratories*, Vol. 1, No. 2).—A fundamental discovery as yet unevaluated in terms of practical application, "the first clear-cut evidence for mitosis in bacteria," was reported to the Fifth International Congress of Microbiology at Rio de Janerio. Drs. Edward D. DeLamater and Stuart Mudd of Philadelphia used new techniques for staining and fixing, which included a quick freezing process, to observe chromosomes in the nucleus of the microorganism, *Bacillus megatherium*. Chromosomes elongated into delicate beads; shortened, condensed and thickened; later were seen as two dense round bodies and a bar, then as beads. Thus, bacteria apparently go through the same complex process as human cells in dividing to multiply.